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System Handbook

Advanced Communications Technology Satellite

NASA

National Aeronautics and
Space Administration

Lewis Research Center
Cleveland, Ohio 44135

ACTS SYSTEM HANDBOOK
REVISION CHANGE INDEX

REV #	DATE	PAGES AFFECTED	NAME/GENERAL DESCRIPTION
1	10/11/91	v, B-24, -24a, -24b	Add description of down-link upconverter spurious signals
2	08/24/92	ii-ix AA-1 Appendix B	Update front matter Update appendix A Add appendix B
3	09/30/93	Minor editorial changes have been made to the entire document. Substantial changes have been made to the following pages: A-1 through A-18, B-3, B-4, B-8, B-10, B-11, B-14, B-15, B-17, B-18, B-28, B-30, C-7, D-1 through D-7, AA-1	Update sections A,B,C, and D

FOREWORD

This handbook was written by Peter A. Lowry of NASA Lewis Research Center. Many other people were involved in helping compile and produce the final version. Thanks goes to everyone involved and a special thanks for their extra effort and help to

Robert Alexovich, Analex Corporation
Robert A. Bauer, NASA Lewis Research Center
S. Joseph Campenella, Comsat Laboratories
William Cashman, Martin Marietta Astro-Space
Thom A. Coney, NASA Lewis Research Center
John Graebner, Martin Marietta Astro-Space
Richard Moat, Motorola
Larry Palmer, Comsat Laboratories
Mark S. Plecity, NASA Lewis Research Center
Carol A. Vidoli, NASA Lewis Research Center

For additional information regarding this handbook or the ACTS Experiments Program please contact

ACTS Experiments Office
ATTN: Mark S. Plecity, MS 54-6
NASA Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135
(216) 433-2012

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SECTION A

ACTS SYSTEM OVERVIEW

INTRODUCTION

The Advanced Communications Technology Satellite (ACTS) is a key element in the goal of NASA's Advanced Communications Program to develop high-risk, advanced communications satellite technology usable in multiple frequency bands to support our nation's future communications needs. Realization of this goal will enable growth in capacity and effective utilization of the frequency spectrum and will maintain the United States preeminence in satellite communications. The NASA ACTS Program sponsors the development and flight testing of this high-risk, advanced communications satellite technology. Using multiple, dynamically hopping spot beams and advanced onboard switching and processing systems, ACTS will pioneer new vistas in communications satellite technology.

Key technologies to be validated as part of the ACTS Program include

(1) Multibeam antenna - A rapidly reconfigurable pattern of hopping beams and fixed spot beams

(2) Baseband processor - A high-speed digital processor onboard the satellite that increases transponder capability over current technology by routing individual, circuit-switched messages

(3) Microwave switch matrix - A dynamic reconfigurable microwave intermediate-frequency switch capable of routing high-volume, point-to-point and point-to-multipoint traffic

(4) Ka-band components - Flight and ground segment hardware at 20 and 30 GHz

(5) Network control - Advanced algorithms to provide flexible, efficient demand-assigned multiple access communications

(6) Adaptive compensation for signal level changes due to rain - Techniques such as forward error correction, burst rate reduction, and uplink power control to automatically adjust for fades.

SYSTEM ELEMENTS

The overall ACTS system consists of the flight segment and the ground segment. The flight segment comprises the flight system, the spaceborne support equipment, and the perigee stage that is used to move the flight system from the shuttle parking orbit into the geostationary transfer orbit. The flight system includes the advanced-technology payload and the spacecraft bus, which provides support functions to the payload.

The ACTS ground segment comprises the ACTS master ground station, the satellite operations center, and the experimenter terminals. The ACTS master ground station is located at the NASA Lewis Research Center, Cleveland, Ohio, and the satellite operations center is in East Windsor, New Jersey. The ACTS master ground station includes the NASA ground station, the master control station, the microwave switch matrix-link evaluation terminal, and the command, ranging, and telemetry ground equipment. The NASA ground station consists of a radiofrequency terminal, two traffic terminals, and a reference terminal. The master control station provides network control for the baseband processor mode of operations. The primary stationkeeping function is performed at the satellite operations center, which is linked through a terrestrial line to the Ka-band command, ranging, and telemetry equipment at the ACTS master ground station. (See fig. A-1.)

The C-band telemetry, tracking, and command ground stations located on Guam and in Carpentersville, New Jersey, and the satellite operations center will be used to support the ACTS mission during transfer orbit operations. The Martin Marietta Alpha station (Carpentersville, New Jersey) can also be used to back up the master ground station for flight system control after ACTS is injected into geosynchronous orbit. The ACTS system elements are presented in figure A-2.

ACTS PHYSICAL CHARACTERISTICS

The on-orbit configuration of the satellite is shown in figure A-3. After the spacecraft is placed on orbit, the solar panels will be extended and the two main reflectors of the multibeam antenna unfolded. Note that there are two antenna subsystems: one for receiving and one for transmitting. These are designed to give approximately the same gains and coverages at both the uplink (receiving) and the downlink (transmitting) frequencies. Table A-1 lists the physical characteristics of the satellite.

TABLE A-1.—SPACECRAFT ON-ORBIT CHARACTERISTICS

Weight, lb	3250
Transmitting antenna diameter, ft	10.8
Receiving antenna diameter, ft	7.2
Steerable antenna diameter, ft	3.3
Length (across main reflectors), ft	29.9
Width (across solar arrays), ft	47.1
Height (from separation plane), ft	15.2
Electric power (beginning of life), W	1856
Total area of solar arrays, ft^2	134.5
Stationkeeping accuracy, deg	0.05
Antenna-pointing accuracy, deg	0.025
Orbit location (longitude)	100° W
Experiment period, yr	2
Propellant capacity, yr	4

SYSTEM FUNCTIONS

In the flight system the multibeam communications package performs receiving, switching, amplifying, and transmitting functions for Ka-band time-division multiple access (TDMA) communications signals. The multibeam antenna has fixed beams and hopping spot beams that can be used to service traffic needs on a dynamic basis. In addition, the receiving antenna provides signals to the autotrack receiver, which generates input error signals to the attitude control system for spacecraft pointing operations. The multibeam antenna,

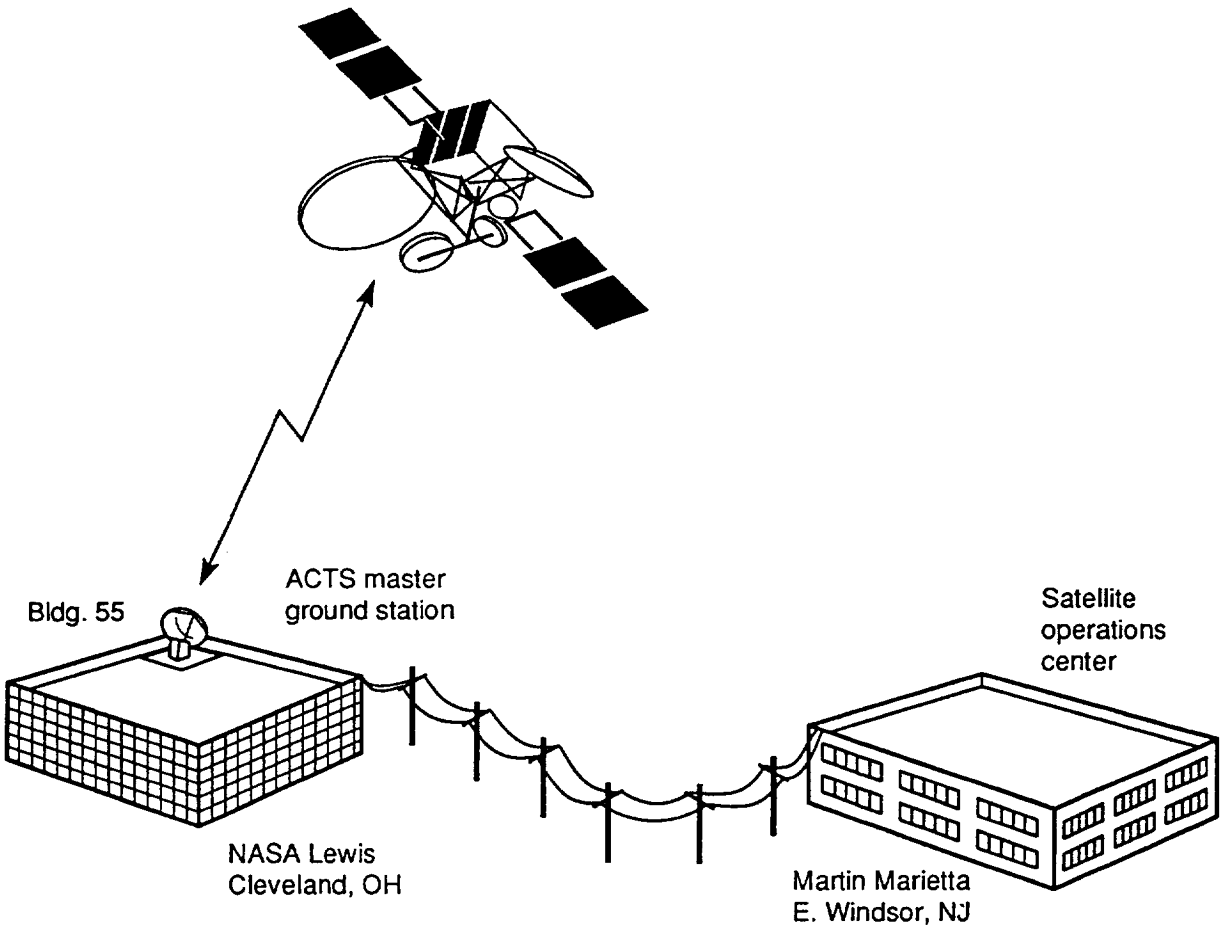


Figure A–1.—Control of ACTS housekeeping functions.

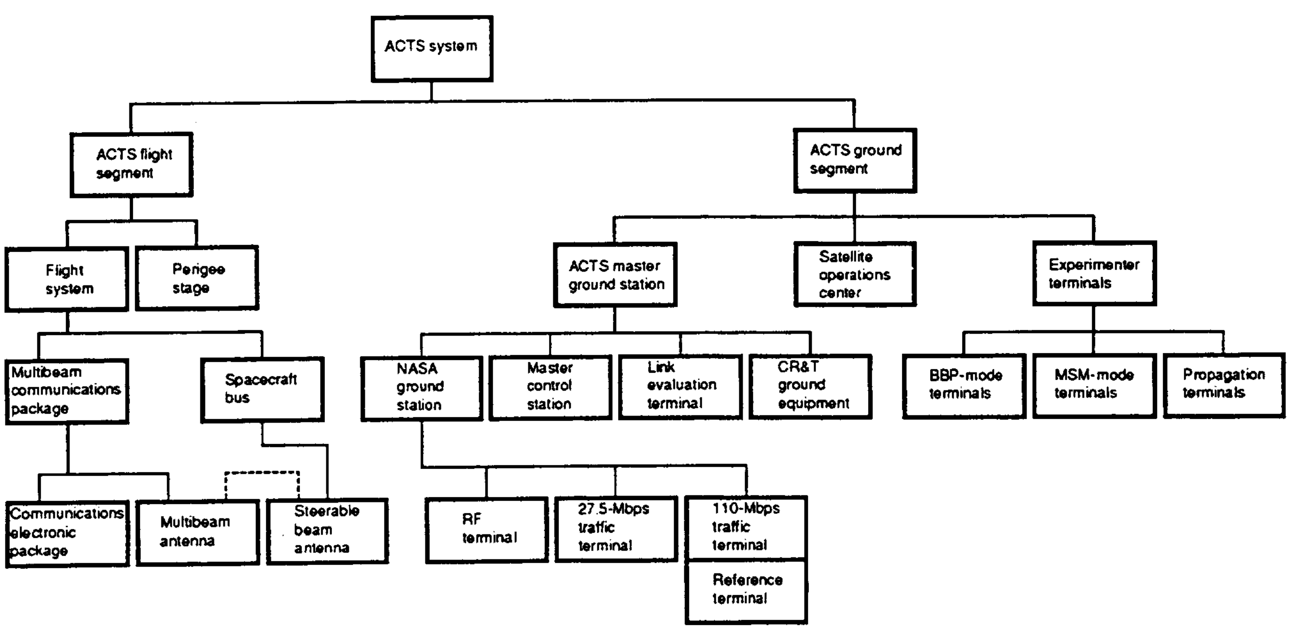


Figure A–2.—ACTS system elements.

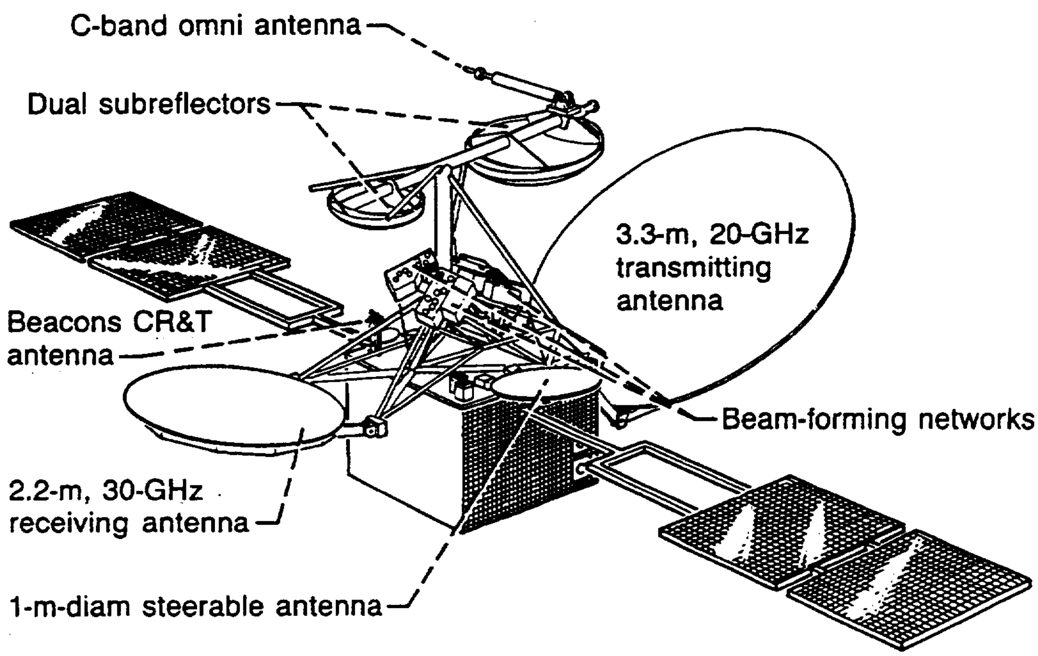


Figure A–3.—On-orbit configuration of ACTS.

which consists of offset Cassegrain systems and a beam-forming network (BFN), provides hopping beams for independent coverage of the east and west scan sectors, plus coverage for isolated locations outside either sector, and three fixed spot beams. Within the beams, access is accomplished by demand-assigned multiple access (DAMA) utilizing TDMA. A steerable beam antenna has been incorporated into ACTS to provide antenna coverage of the entire disk of the Earth as seen from 100° W longitude and to any aircraft or low-Earth-orbiting spacecraft, including the space shuttle, within view of the ACTS.

Low-noise receivers in the multibeam communications package amplify uplinked 30-GHz TDMA signals and downconvert them to 3 GHz. These microwave intermediate-frequency signals are then routed for processing by one of the two radiofrequency communications modes: the baseband processor mode, or the microwave switch matrix mode. For the baseband processor mode of operation the received signals are demodulated, routed, and remodulated by the baseband processor and then passed on to the appropriate transmitting chain. The upconverter and traveling-wave tube amplifier (TWTA) combinations take the 3-GHz TDMA signals, translate them to 20 GHz, and amplify them for downlink to Earth terminals. For the microwave switch matrix mode of operation the received signals are routed dynamically by the microwave switch matrix to the appropriate upconverter and transmitter chain.

The spacecraft bus, the space platform on which communications packages are mounted, provides essential housekeeping functions for the multibeam communications package. The bus structure serves as the base for mounting the electrical and mechanical assemblies of the flight system. The Ka-band command, ranging, and telemetry (CR&T) subsystem receives, checks, and distributes flight system commands from the NASA ground station. This subsystem also collects, formats, and transmits flight system telemetry data. Most multibeam communications package operations are controlled and monitored by the spacecraft bus CR&T subsystem. However, baseband processor programming and status monitoring are normally performed by using control directives and status messages transmitted within the baseband-processor-mode communications channel. All multibeam communications package timing signals and frequencies are generated from a common, highly stable, 5-MHz crystal oscillator. The Ka-band telemetry subsystem also transmits 20- and 30-GHz beacon signals used for rain fade detection. A C-band telemetry, tracking, and command subsystem is employed during transfer orbit operations and as an emergency backup. Except for transfer orbit operations, C band will be used only for spacecraft health emergencies during on-station operations. The attitude control subsystem stabilizes the flight system and controls spacecraft orientation by using autotrack error signals generated by the multibeam communications package. The electric power subsystem provides electric power to the multibeam communications package and the bus from a combination of solar cell arrays and storage batteries.

The operational configuration for the ACTS flight system is shown in figure A-3. During this mission phase the spacecraft is three-axis stabilized with the large antenna reflectors facing the Earth and the solar array panels rotating once per day to track the Sun. During the transfer orbit phase the spacecraft is spin stabilized, and the antenna reflectors and solar array panels are retracted and stowed to provide better load support for these appendages.

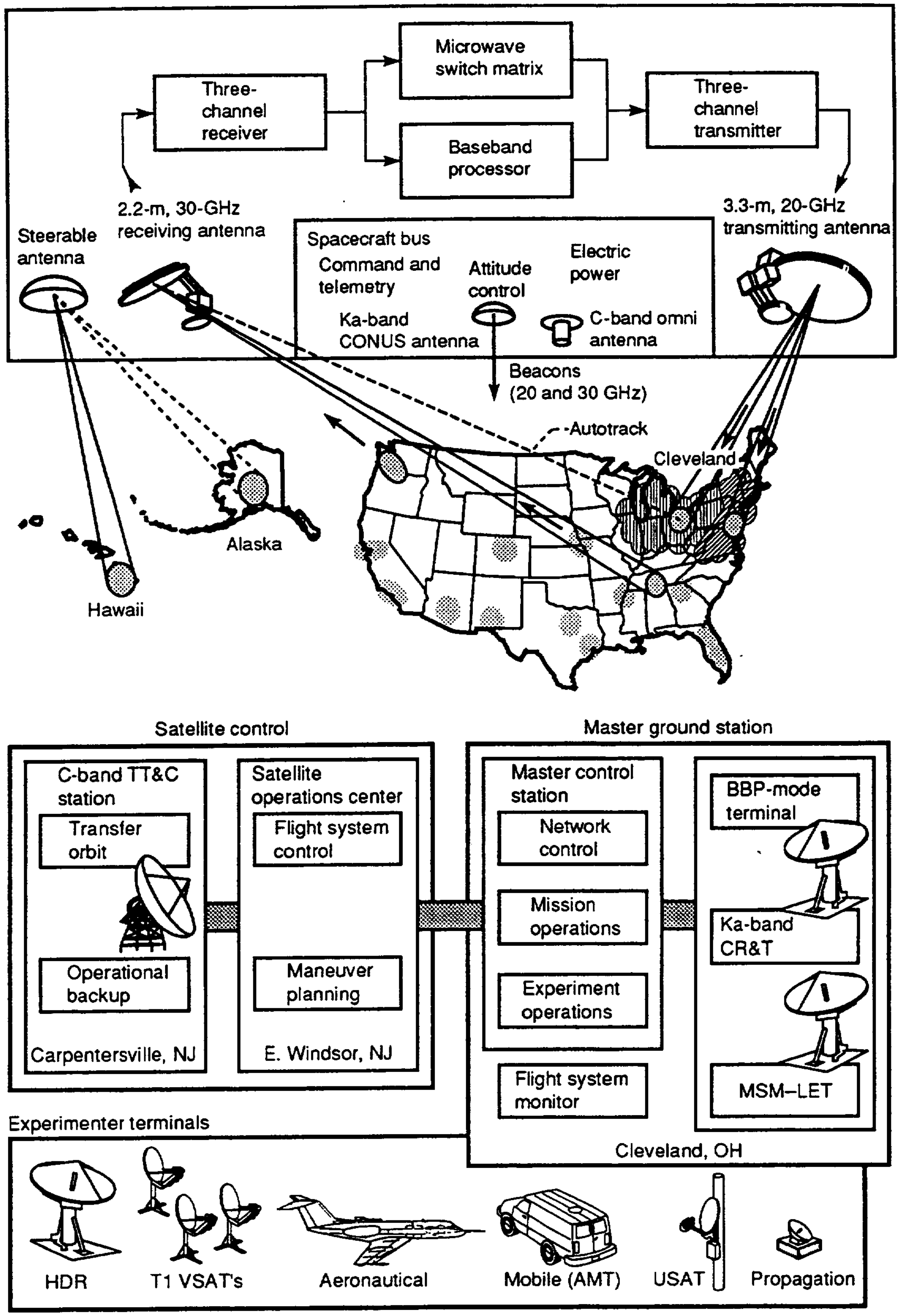


Figure A–4.—ACTS system functional overview.

In the ground segment the NASA ground station upconverts signals for the baseband processor mode of operation to 30 GHz for transmission to ACTS and amplifies and downconverts the 20-GHz baseband-processor-modulated signals received from ACTS. Modulation and demodulation of the baseband communications signal are performed in the NASA ground station. The NASA ground station receives and processes fade beacon data. The master control station provides network control for the spacecraft baseband processor. The microwave switch matrix-link evaluation terminal is located within the ACTS master ground station and provides the capability for on-orbit testing of the microwave switch matrix and the multibeam antenna and for conducting wideband communications experiments. The satellite operations center has primary responsibility for generating flight system commands and for processing and displaying flight system telemetry data. Orbital maneuver planning and execution are also handled by the satellite operations center. The C-band telemetry, tracking, and command station performs flight system command and telemetry functions during the transfer and drift orbit mission phases. It is also available to back up the NASA ground station in the event of anomalies during the operational phase.

The Ka-band experimenter network consists of a variety of ground stations to be operated by industry, universities, and government organizations. These ground stations (frequently referred to as Earth terminals) have varying capabilities ranging from full implementation of microwave-switch-matrix-mode or baseband-processor-mode communications to receiving only beacon signals for propagation modeling. Figure A-4 presents an overview of the ACTS system functions.

FLIGHT SYSTEM TECHNOLOGY

Multibeam Communications Package

The multibeam communications package (MCP) includes most of the advanced hardware technology being implemented in the ACTS system. A simplified block diagram of the package is shown in figure A-5. The multibeam antenna (MBA) consists of two high-gain, offset-feed Cassegrain antenna subsystems: one for reception at 30 GHz, and one for transmission at 20 GHz. The transmitting antenna's main reflector is equipped with a two-axis drive that allows vernier adjustment of the antenna pattern. The antenna subsystems are scaled so that the gains and beam sizes (about 0.25°) are the same in both frequency bands. The multibeam antenna has three fixed spot beams, one pointing at Cleveland, one at Atlanta, and one at Tampa; the receiving feed for the Cleveland beam is also equipped to provide autotrack error signals. The Cleveland fixed beam is horizontally polarized. The Tampa and Atlanta beams are vertically polarized. Vertical polarization is defined by a vector parallel to the north-south direction at the spacecraft. Horizontal polarization is orthogonal to the vertical polarization. Transmitting polarizations are orthogonal to the receiving polarizations. Both the receiving and transmitting portions of the MBA have dual gridded subreflectors that discriminate between polarizations. The MBA also has two pairs of hopping beams; each pair consists of independently hopping uplink and downlink beams. Beam hopping is performed by beam-forming networks (two receiving, two transmitting). Latching ferrite circular switches route signals to and from selected beams. The hopping beams supply

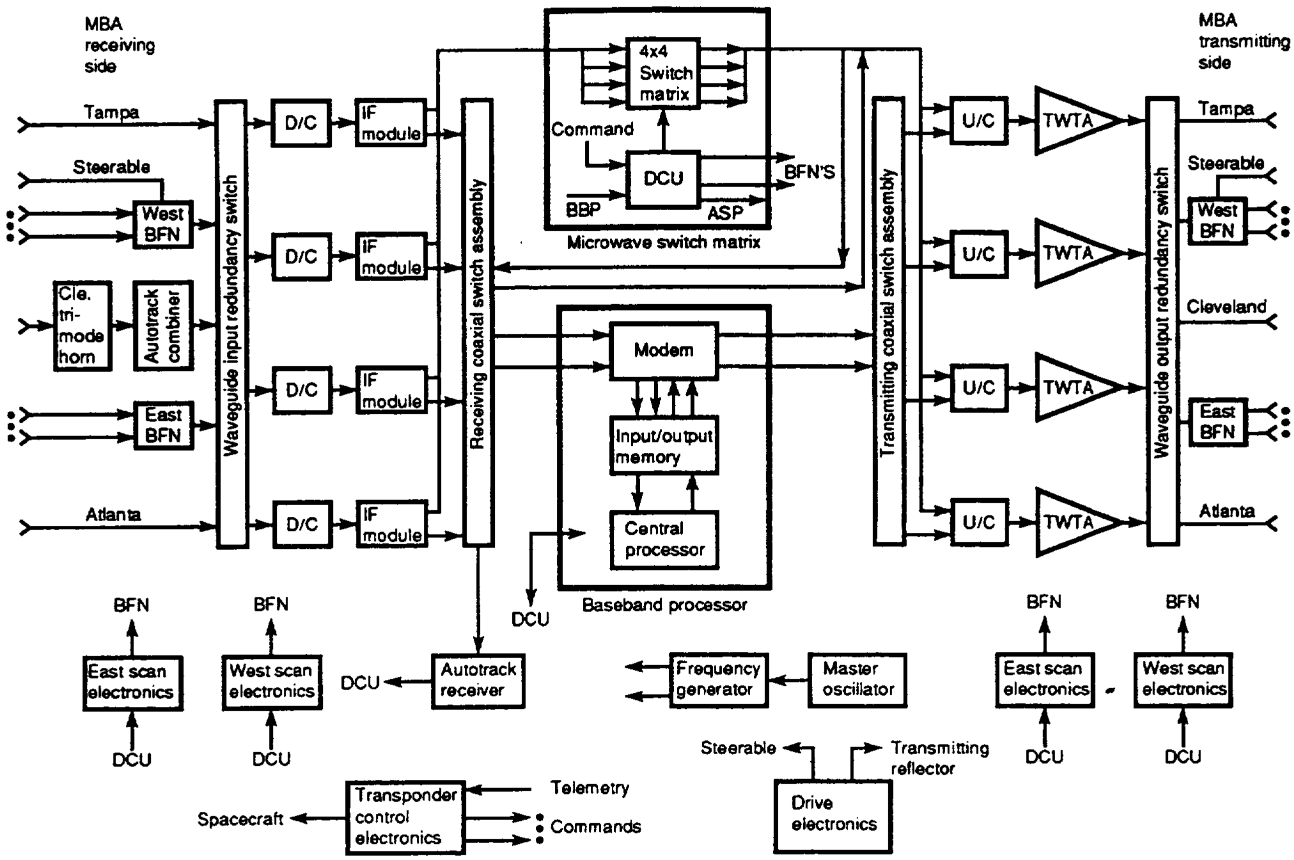


Figure A-5.—ACTS multibeam communications package.

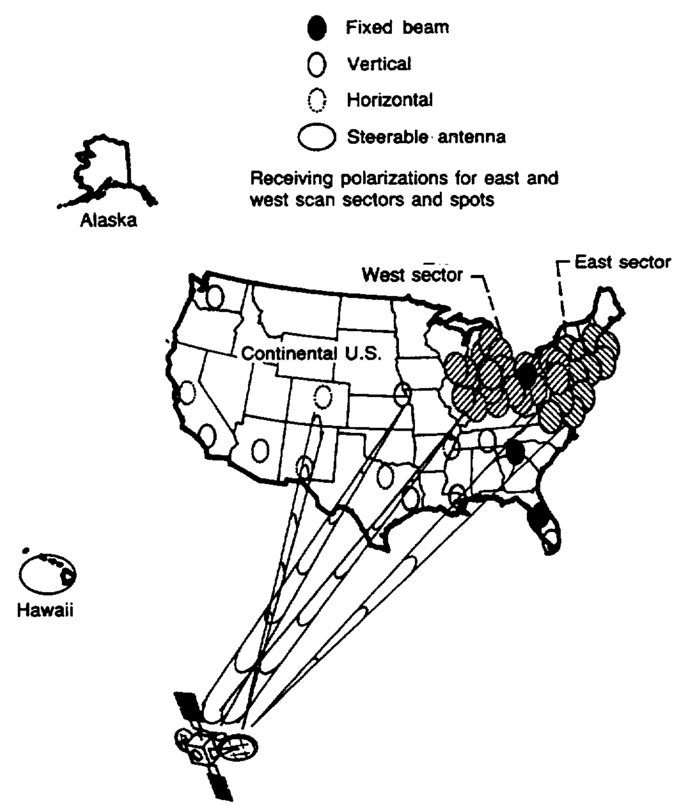


Figure A-6.—Coverages of ACTS antennas.

contiguous coverage in two scan sectors in the northeastern United States plus isolated coverage of 13 other metropolitan areas across the United States. The ACTS multibeam antenna coverage is presented in figure A-6. In addition, the flight system contains a separate, two-axis, motor-driven steerable antenna that is functionally part of the multibeam antenna and can provide spot coverage of the entire disk of the Earth as seen from 100° W longitude (not otherwise provided by the spot beams) and to any aircraft or low-Earth-orbiting spacecraft including the space shuttle, within view of the ACTS. The gain of the steerable antenna is a few decibels less than that of the multibeam antenna.

The receiving antenna and the transmitting antenna are connected to the communications electronics package by waveguide switches. Any pair of beams can be connected to the baseband processor through two of the four low-noise receivers by these switches. In a similar manner any three beams can be connected to any of the intermediate-frequency microwave switch inputs. The transmitting antenna is connected to the four TWTA's by the waveguide output redundancy switches. The outputs of the baseband processor and the microwave switch matrix are connected to the beams of the transmitting antenna through the TWTA's and their drivers. The interconnectivity of these switches allows for a variety of operational configurations with both the baseband processor and the microwave switch matrix.

The low-noise receivers amplify the 30-GHz communications signals from the selected multibeam antenna beams and downconvert them to 3 GHz for routing. So that they can achieve the required low-noise, high-gain performance, the initial amplifying stages of the receiver employ gallium arsenide (GaAs), high-electron-mobility transistors. These devices produce receivers having noise figures of approximately 4 dB across a 1-GHz passband near 30 GHz. The noise figure is the expected average over the life of the satellite.

Baseband Processor

The baseband processor, schematically shown in figure A-7, demodulates incoming signal bursts to digital baseband, stores them, decodes them if they are encoded, routes them to the proper output memory location, encodes them if required, and remodulates them for transmission. The TDMA signals received and transmitted by the baseband processor are modulated by using serial minimum shift keying (SMSK). The SMSK modulation technique is spectrally efficient. The null-to-null bandwidth is 1.5 times the baseband symbol rate. It also provides minimum regrowth of sidebands when the signal is passed through devices such as limiting amplifiers and saturated TWTA's. The use of 64-bit words together with a 1-msec framing rate in the baseband processor provides 64-kilobit-per-second (kbps) circuits. The baseband processor simultaneously accepts TDMA signals from two uplink hopping beams. In each beam a single 110-megasymbol per second (Msps) signal or two simultaneous 27.5-Msps signals can be received on a dynamically switchable basis. A symbol is a state in waveform of a carrier modulated by a discrete data stream. For SMSK modulation there are two types (+1 or -1). A bit refers to information content. Thus for data that are uncoded, one symbol equals one bit. For data coded by a rate -1/2 code, for example, two symbols equal one bit.

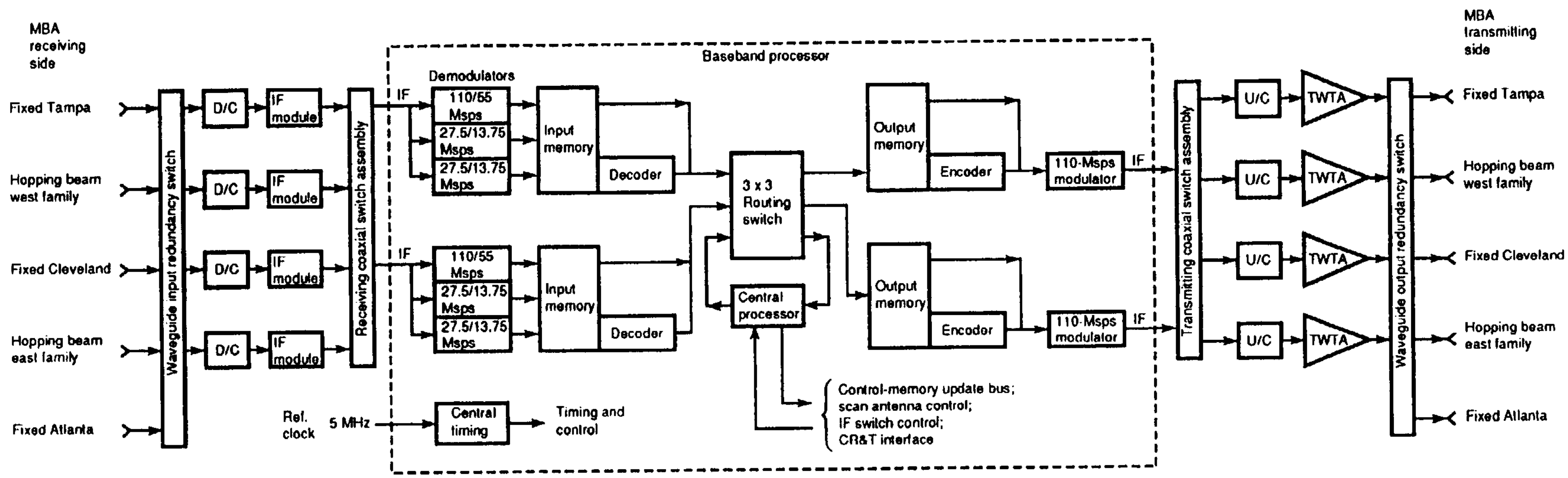


Figure A-7.—Functional diagram of baseband processor.

Although the input to the baseband processor accepts data that are modulated at two different data rates, the output is limited to 110 Msps for uncoded operation. For coded operation, both on the input and the output, the symbol rates are reduced by one-half. Thus, in figure A-7 the 110/55 Msps represents 110 Msps uncoded or 55 Msps coded. Similarly, 27.5/13.75 Msps represents uncoded or coded rates. The output symbol rates are 110 Msps for uncoded operation and 55 Msps for coded operation. The baseband processor output is connected to two of the TWTA driver amplifiers for transmission to the ground. The net result of coding produces an information (bit) rate equal to one-fourth the uncoded rate. Rain fade margins of up to 10 dB can be accommodated by forward error correction (FEC) and burst rate reduction.

The baseband processor operates under stored program control, and the control memories are updated by the master control station as needed to provide demand-assigned multiple access operation. The control memories direct the actions of demodulators, decoders, the baseband routing switch, encoders, and modulators, as well as the sequence of the multibeam antenna's hopping beams.

The high-speed processing requirements coupled with the space environment posed significant challenges to the baseband processor design. Custom large-scale integrated chips were developed to provide certain high-speed functions of the SMSK demodulators, control-memory update controllers, and decoders, as well as to minimize size, weight, and power requirements. In addition, complementary metal oxide semiconductor memory chips are employed to minimize power consumption and to reduce susceptibility to space radiation effects.

Microwave Switch Matrix

The microwave switch matrix is a solid-state, programmable, four-by-four "crossbar" switch that directly connects the four low-noise receivers to the four transmitters. The system was designed for operation with a maximum of three transmitters operating at one time, thus providing four-for-three redundancy.

Figure A-8 schematically illustrates the microwave switch matrix's architecture. The simple connect-disconnect feature of these switches allows a variety of connections from input to output, ranging from no connections to having three inputs connected to three outputs.

At no time will more than one input be allowed to be connected to any one output. The waveguide redundancy switches permit the selection of any three inputs from the five multibeam antenna ports and likewise the selection of any three outputs. The waveguide switches are electromechanical and will generally be fixed for the duration of an experiment. The microwave switch matrix can route microwave signals over a 1-GHz bandwidth between 3 and 4 GHz. The less than 100-nsec switching time of the GaAs field-effect transistor amplifier switches permits efficient dynamic routing for use with TDMA communications traffic.

The microwave switch matrix can operate in one of two modes: the static mode, or the dynamic mode. In the static mode the switches are held fixed and communications through the satellite are by a "bent pipe" mode. In this mode a

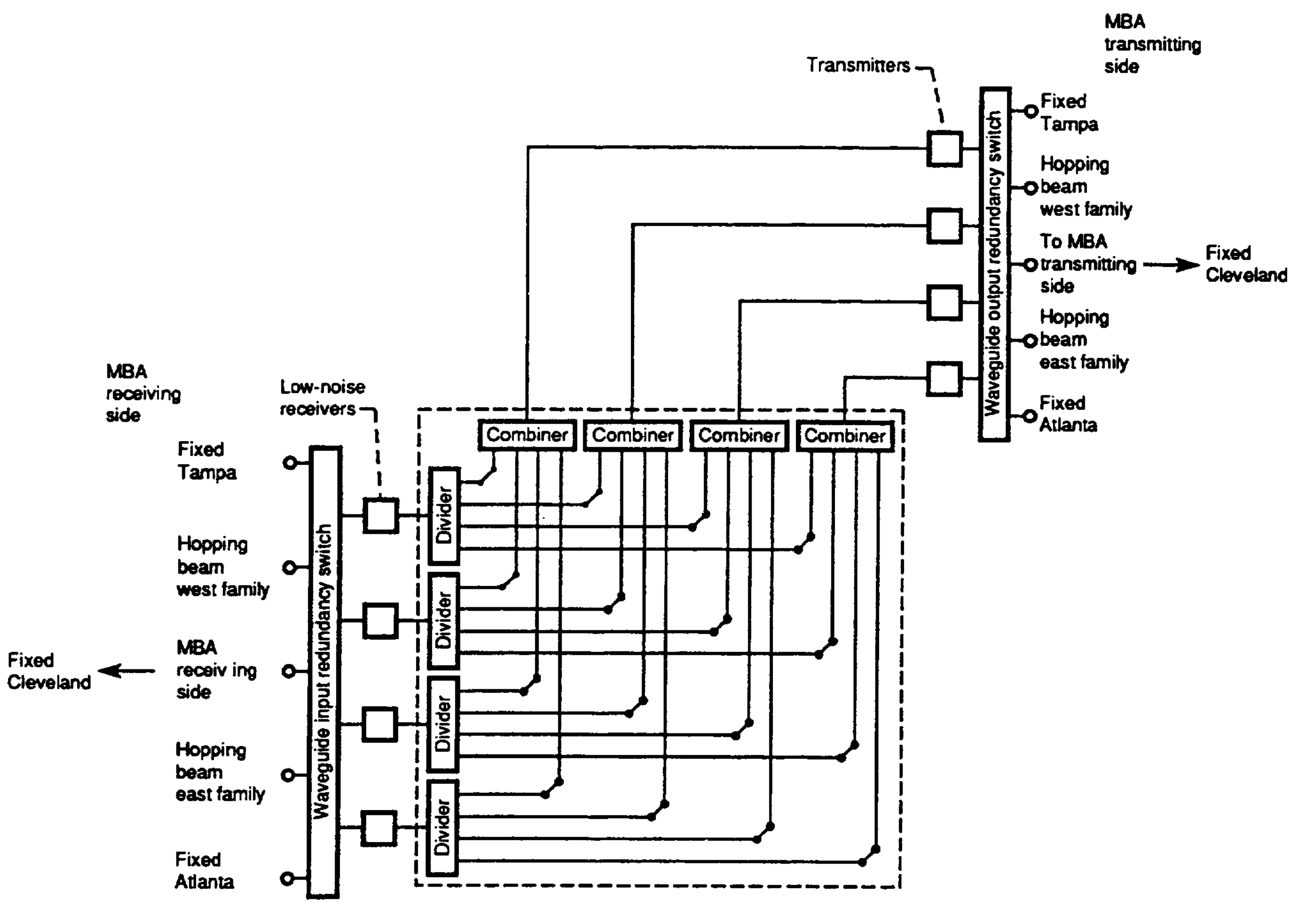


Figure A–8.—Microwave-switch-matrix-mode configuration.

variety of traffic types can be used for experiments with the 1-GHz bandwidth, such as frequency-division multiple access (FDMA) or very high-burst-rate TDMA. In the dynamic mode the rapid switching of the communications traffic forces the modulation method to be of digital format. A variety of modulation forms are available, such as binary phase-shift keying (BPSK), quaternary phase-shift keying (QPSK), and other digital forms.

The microwave switch matrix is controlled only through the command system. The 5-kbps command link rate limits the rate at which the control memories can be reprogrammed.

An optional feature provided in the microwave switch matrix mode of operation is a blink state. The blink state is a period in which all the switches are open (no signal transmitted). The period length is programmable. This feature is provided for terminals that use microwave-switch-matrix-mode communications in order to synchronize the communications channels every 60 sec.

SPACECRAFT BUS

The spacecraft bus provides essential housekeeping functions for the multibeam communications package. It is based on the RCA series 4000 design used in several commercial communications satellites, but certain modifications have been made to support the unique requirements of the ACTS mission including command and telemetry functions at Ka band and the high-rate (5000 bps) command capability required by the MCP. Also, a new high-temperature solar array substrate was developed to meet shuttle thermal requirements.

Bus Structure

The spacecraft bus structure is a rectangular box with a cylindrical center structure that houses the apogee kick motor. The height of the box has been increased from the series 4000 design in order to optimize balance and inertia ratio during transfer orbit when the flight system is spin stabilized. The structure box outer dimensions are 80 in. by 84 in. by 70 in. high. The north and south sides are each divided into three panels. These panels are used to mount most of the spacecraft bus and multibeam communications package electronics equipment. An exploded view of the structure and attached equipment is shown in figure A-9.

Command, Ranging, and Telemetry Subsystem

The ACTS command, ranging, and telemetry subsystem consists of the antennas, receivers, and transmitters that provide command reception, telemetry transmission, and ranging during all mission phases. There are two command subsystems. Both systems use "tones" to frequency modulate the uplink command carrier. The low-rate commands (100 bps or less) use the three tones 5, 8, and 11 kHz (one, zero, and execute frequencies, respectively). The low-rate commands can be executed manually. They are used to control the spacecraft bus and to turn on or turn off the power supplies to the various portions of the multibeam communications package. The high-rate commands use a modified satellite ground link system format at 5 kbps. The high-rate command tones are 65, 80, and 95 kHz for the start/stop bit "S," zero, and one states,

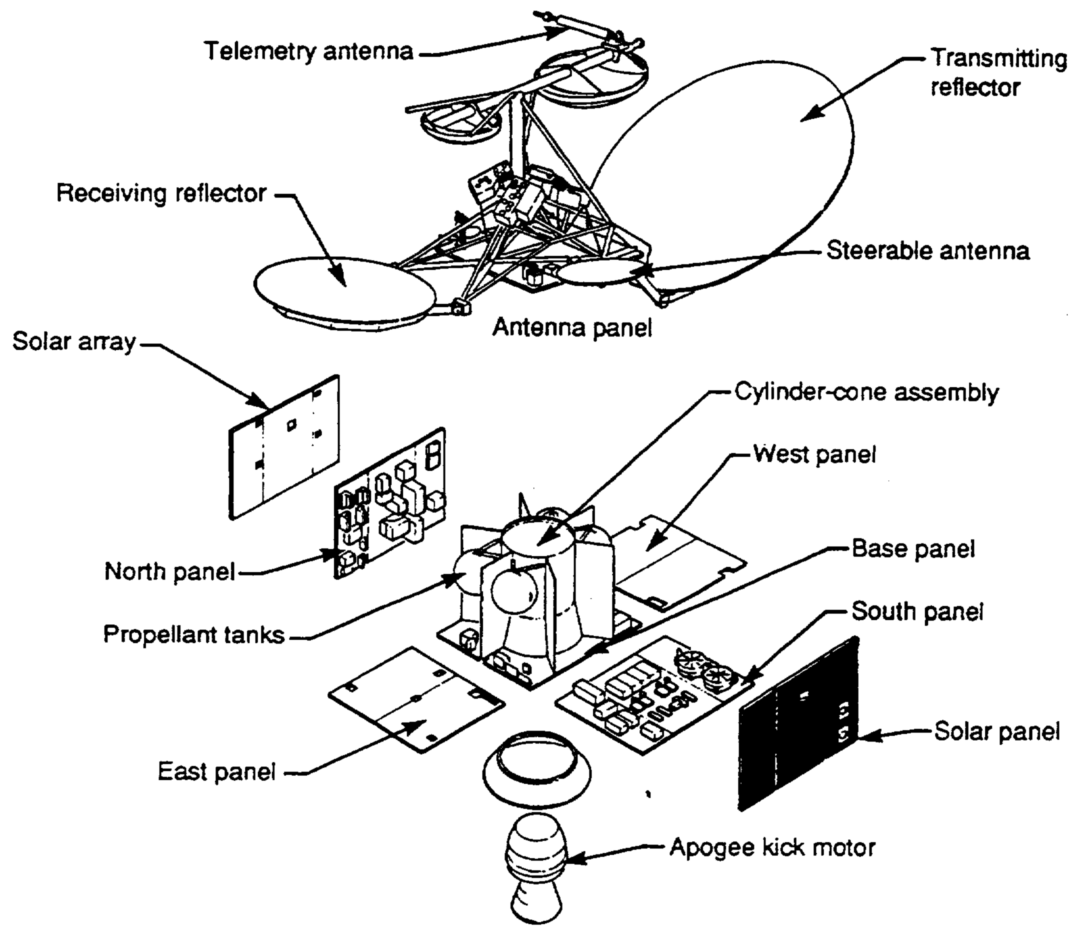


Figure A-9.—Exploded view of ACTS.

respectively. High-rate commands are automatically executed upon correct decoding. They are used to program the multibeam communications package. In the preoperational phase (during transfer orbit, drift to station, and station acquisition) the spacecraft bus commands are sent through a C-band link. Omnidirectional antennas are used to receive these signals. During the operational phase the Ka-band link is used to control the spacecraft. High-rate commands can be sent only on the Ka-band link. The Ka-band CR&T antenna covers only the continental United States (CONUS).

During orbit insertion and other preoperational phases the low-rate-command verification and other telemetry is sent through a C-band link. The telemetry is modulated on one of the two Ka-band downlink beacons during the operational phase. Three subcarriers are used at 14.5, 32, and 64 kHz on the telemetry carriers. The 14.5-kHz subcarrier is used for analog data. The 64-kHz subcarrier contains the 1000-bps telemetry as pulse-code-modulated data. The 32-kHz subcarrier is used as a placeholder for the ranging tones. This permits operational phase ranging to be done simultaneously with the telemetry signal by switching the ranging tones with the 32-kHz subcarrier while maintaining constant carrier power for fade measurements.

Attitude Control Subsystem

The ACTS attitude control subsystem consists of sensors, processing logic, torquer coils, and thrusters. It employs momentum bias for flight system three-axis stabilization on station. Spacecraft pitch is controlled by varying the momentum wheel assembly speed. Pitch reference is provided by either the autotrack (when available) or the Earth sensor. Spacecraft roll and yaw are controlled by applying current to magnetic torquing coils. Roll reference is provided by either the autotrack signal or the Earth sensor; yaw reference is always obtained by the Sun sensors. The attitude control subsystem also manages thruster firing to augment control of all three axes when the nominal control range of the momentum wheel assembly and the roll and yaw torquers has been exceeded. When operational, the multibeam communications package provides autotrack error signals necessary for the attitude system processor to meet the 0.025° antenna-pointing accuracy requirement. These error signals are referenced to the command carrier uplinked from Cleveland through the spot beam fixed on Cleveland. The autotrack receiver uses one of the multibeam communications package low-noise receivers to amplify the error signals and to perform the first signal downconversion. Therefore, the autotrack receiver is inoperative when the multibeam communications package is unavailable, such as during eclipse periods. During these times Earth and Sun sensors supply the reference signals to the attitude control system.

Propulsion Subsystem

The ACTS propulsion subsystem consists of a reaction control subsystem and an apogee kick motor. The catalytic thrusters, propellant tanks, and plumbing make up the reaction control subsystem, which is configured as a pressurized blowdown system with hydrazine as the propellant and helium as the pressurant. The thrusters are used primarily for orbit adjustment maneuvers but also participate in certain attitude control functions. The apogee kick motor, a solid-propellant motor of the Thiokol STAR-37 FM class, is fired to move the satellite from the elliptical transfer orbit to the circular geostationary orbit.

Electrical Power Subsystem

The ACTS electrical power subsystem is a direct-energy-transfer configuration consisting of solar array panels, storage batteries, and power regulation equipment. Primary power is generated by high-efficiency solar cells mounted on deployed panels that are motor-driven to remain facing the Sun. Array power is distributed to the flight system loads and is also used to charge two nickel-cadmium storage batteries. The batteries are rated at 19-A-hr capacity and supply essential bus loads during solar eclipse periods. However, because their capacity is insufficient to provide adequate power for the multibeam communications package during eclipse periods, experiment operations are not planned during these periods. The solar array subsystem is designed to provide 1856 W of peak power at the beginning of spacecraft on-orbit operations.

Thermal Control Subsystem

The ACTS thermal control subsystem is essentially a passive configuration that relies on selection of finishes and multilayer insulation blankets to maintain proper temperatures. In addition, thermostatically controlled heaters are used to augment the passive system, when required, in order to hold temperatures in the design range. Heat pipes are used under the traveling-wave tubes and the baseband processor to remove heat efficiently from these high-heat-density components and thus limit the upper extreme of the temperature range.

GROUND SEGMENT TECHNOLOGY

The ACTS master ground station, located at the Lewis Research Center, contains the radiofrequency and signal-processing equipment that supports both the baseband processor and microwave switch matrix modes of operation as well as the Ka-band CR&T signals. Two radiofrequency terminals are provided, one for each mode of operation. Both terminals employ nominally 5-m-diameter Cassegrain antennas. These antennas provide reception at 20 GHz and transmission at 30 GHz for the respective modes of operation. The linearly polarized signals are cross polarized between the receiving and transmitting signals, allowing simultaneous operation of the transmitters and receivers. The Ka-band CR&T subsystem uses the NASA ground station radiofrequency antenna. The 27.5-GHz uplink fade beacon will also be received on this antenna. Rain fades are detected by monitoring the amplitude levels of the flight system beacons. The beacons are positioned in frequency at the edges of the uplink and downlink bands. The baseband-processor-mode TDMA subsystem includes the modems and TDMA controllers needed to participate in the baseband processor networks. The baseband processor modems employ SMSK modulation and operate at uncoded rates of 27.5 or 110 Msps on the uplink and an uncoded rate of 110 Msps on the downlink. They can reduce the symbol rate by one-half and employ a rate-1/2, convolutional forward-error-correcting code to compensate for rain fade conditions. This application of rate reduction and forward-error-correcting coding is under computer control. The baseband processor TDMA controllers interact with the master control station's network control processor for network coordination, as well as with external experimenter communications traffic.

The master control station contains the computer hardware and software to coordinate TDMA traffic flow. It uses a VAX 8600 computer to direct the real-time network activities, to develop TDMA burst time plans, and to respond to demand-assignment requests. The off-line functions of archiving and retrieving experiment data are the responsibility of the master control station.

The microwave-switch-matrix-mode subsystem includes the modems and controllers required to provide 110- and 220-Msps TDMA traffic through the link evaluation terminal. NASA Lewis Research Center designed the link evaluation terminal to be used for the on-orbit testing and evaluation of the microwave switch matrix and the multibeam antenna and for conducting wideband communications experiments. The modem employs SMSK modulation. Output power control is provided to compensate for signal fading due to rain. For communications traffic using other forms of modulation an input port connection is provided at the intermediate-frequency level, which is nominally in the 3- to 4-GHz band. The microwave switch matrix controller interacts with the master control station for network coordination of TDMA traffic.

NETWORK TECHNOLOGY

The ACTS system supports two types of satellite switching networks: the baseband processor mode, and the microwave switch matrix mode. In the baseband-processor-mode network Earth terminals can use 1.2-, 2.4-, 3-, or 5-m-diameter antennas, depending on location within the antenna beam, but must use SMSK modulation. Data are uplinked at burst rates of 27.5 or 110 Msps, depending on terminal capacity requirements, and are downlinked at 110 Msps. The baseband-processor-mode network is designed to accommodate 15 dB of uplink fade and 6 dB of downlink fade and still achieve an end-to-end bit error rate of 10^{-6}. Fade compensation is implemented automatically by reducing the symbol rate by a factor of 2 and using a rate-1/2 convolutional forward-error-correcting code to produce a 10-dB gain in performance at the expense of longer data transmission intervals.

The baseband processor mode of operation uses the baseband processor and the multibeam antenna hopping beams in the multibeam communications package to receive and demodulate uplink TDMA signals, route and resequence the traffic, and modulate and transmit the downlink signals to the specified destinations. At a given time instant the baseband processor can service two uplink beams, each beam containing one 110-Msps uplink channel or two frequency-multiplexed 27.5-Msps uplink channels, plus two downlink beams with each beam containing one 110-Msps downlink channel (fig. A-10). Capacity requests are handled on a demand-assigned multiple access basis in multiples of 64 kbps. The TDMA frame is 1 msec in duration, and changes in the TDMA burst time plan take place at the start of specified 75-msec superframes. Depending upon capacity requirements the ACTS system can service as many as 40 Earth terminals per TDMA frame.

The baseband-processor-mode network operates under the direction of the master control station. Two-way in-channel orderwires[1] are used to control Earth terminal actions, such as TDMA acquisition and synchronization, requests for call setup and teardown, and implementation of fade compensation. In-channel control directives are used for programming the baseband processor to establish traffic-routing patterns and capacity allocations.

In the microwave switch matrix mode of operation using the link evaluation terminal, the network is designed to accommodate 12 dB of uplink fade in order to maintain a bit error rate of 10^{-6}. Fade compensation is implemented automatically by increasing the uplink power as much as 8 dB.

The microwave-switch-matrix-mode network uses the switch matrix and the multibeam antenna in the satellite to receive, route, and transmit TDMA signals. Using the multibeam antenna's beam-forming network rather than the fixed beam will result in a small reduction in margin. The microwave switch matrix's TDMA frame is 1 msec in duration. Changes in the TDMA burst time plan take place at the start of specified 1-min superframes. Depending upon capacity requirements the ACTS system can service as many as nine Earth terminals per frame on a full-connectivity basis. The 5-kbps CR&T uplink channel is employed for programming the microwave switch matrix.

EXPERIMENTS

The ACTS program has a significant experiments content. In addition to the planned flight verification of the development technology, experimenters from U.S. commercial, university, and governmental organizations have been encouraged to devise and conduct experiments that will pave the way for further application of ACTS technology to future satellite advanced communications systems.

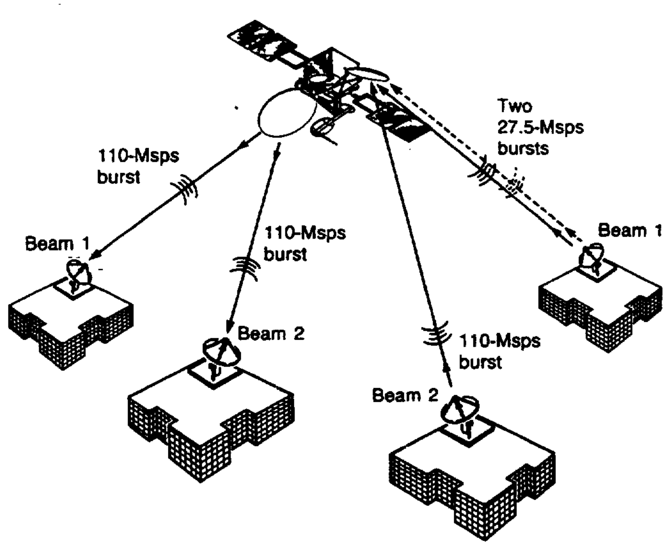


Figure A-10.—Example of instantaneous transmission of messages via baseband processor and hopping beams.

[1]In-channel orderwires are time slots allocated in the communications channels.

SECTION B

SPACECRAFT AND EARTH TERMINAL HARDWARE
AND NETWORK CONTROL SOFTWARE

MULTIBEAM COMMUNICATIONS PACKAGE

The multibeam communications package contains the communications elements of the ACTS spacecraft. Both low- and high-burst-rate signals are received, routed, and retransmitted by this hardware. Several elements not found in conventional bent-pipe repeater transponders are employed. Discussion of these unique elements follows.

Multibeam Antenna

The 1-μsec switching speed and the programmable feature of the communications antennas adds a new dimension to satellite communications. If we envision the diversity in the communications channels along two axes, where the frequency domain lies along the X-axis and the time domain along the Y-axis, the ACTS hopping beams introduce a third dimension along a Z-axis in the spatial domain. (See fig. B-1.)

Historically, communications capacity through satellites was first achieved by dividing the frequency spectrum into channels with analog frequency modulation. The information to be transmitted would directly modulate the carrier (e.g., television signals), or subcarriers would be modulated with voice signals or other information, further dividing the frequency spectrum. This method of diversifying the channel bandwidth is referred to as frequency division multiplexing (fig. B-2). Reception of information via this means is analogous to selecting a channel on a television set.

The development of integrated circuits made possible low-cost complex digital circuitry that enabled the use of digitized information with improvements in performance. Thus came about the concepts of encoding information and compressing it into short timeframes or slots. This "time sharing" is shown diagrammatically in figure B-3 and is referred to as time-division multiple access. This gives us the second axis in figure B-1.

The hopping multibeam antenna adds a new dimension, a spatial one, to the satellite domains. The third axis (in fig. B-1) is labeled in terms of the number of locations, or spots, on the ground. Figure B-4 locates the spots on the ground for each beam. Information transmitted either to or from the satellite can be mathematically represented as data (f,t,s), where f is the frequency variable, t the time variable, and s the spatial variable.

The multibeam antenna consists of two sides: the receiving antenna, and the transmitting antenna. The receiving main reflector is 2.2 m in diameter and the transmitting main reflector is 3.3 m in diameter. These dimensions provide nominally equal gains for each antenna. Each antenna has five ports, two beam-forming-network ports and three fixed-beam ports. The receiving antenna is connected to the four low-noise receivers of the multibeam communications package via five switches known as waveguide input redundancy switches (WIRS). Any pair of ports can be connected to the baseband processor via the low-noise receivers through these switches (fig. B-5(a)), or in a similar manner to any of the intermediate-frequency microwave switch inputs (fig. B-5(c)). The transmitting antenna is connected to the four TWTA's through the waveguide output redundancy switches (WORS). Examples of connection to the baseband processor and microwave switch matrix are shown in figures B-5(b) and (d). This flexibility allows for a variety of operational configurations.

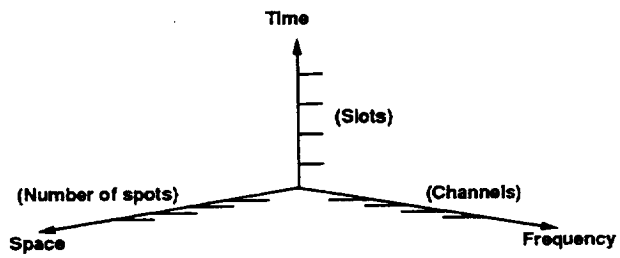


Figure B-1. — Three-dimensional representation of communications diversity.

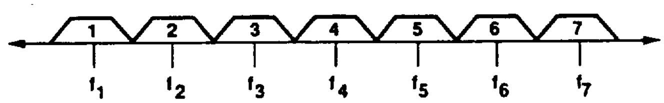


Figure B-2. — Frequency division of communications channel.

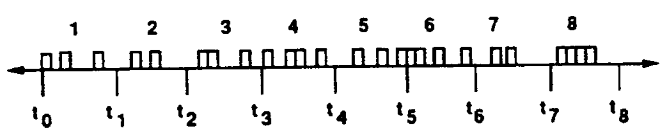


Figure B-3. — Time division of communications channel.

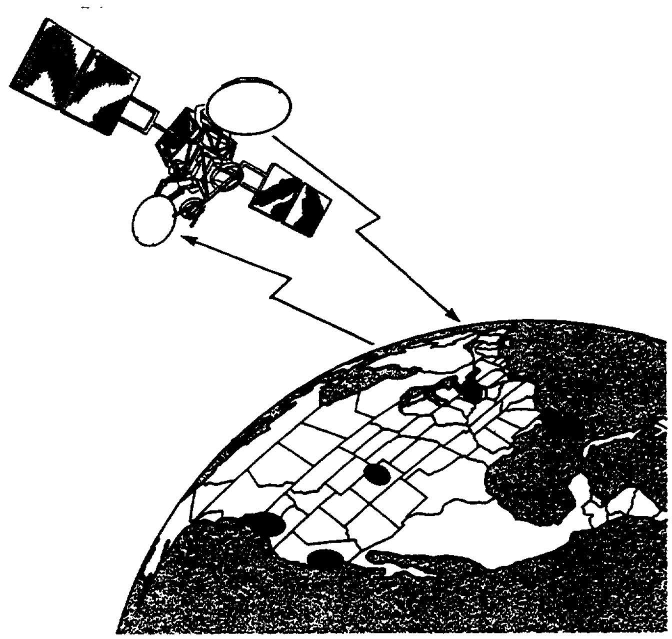
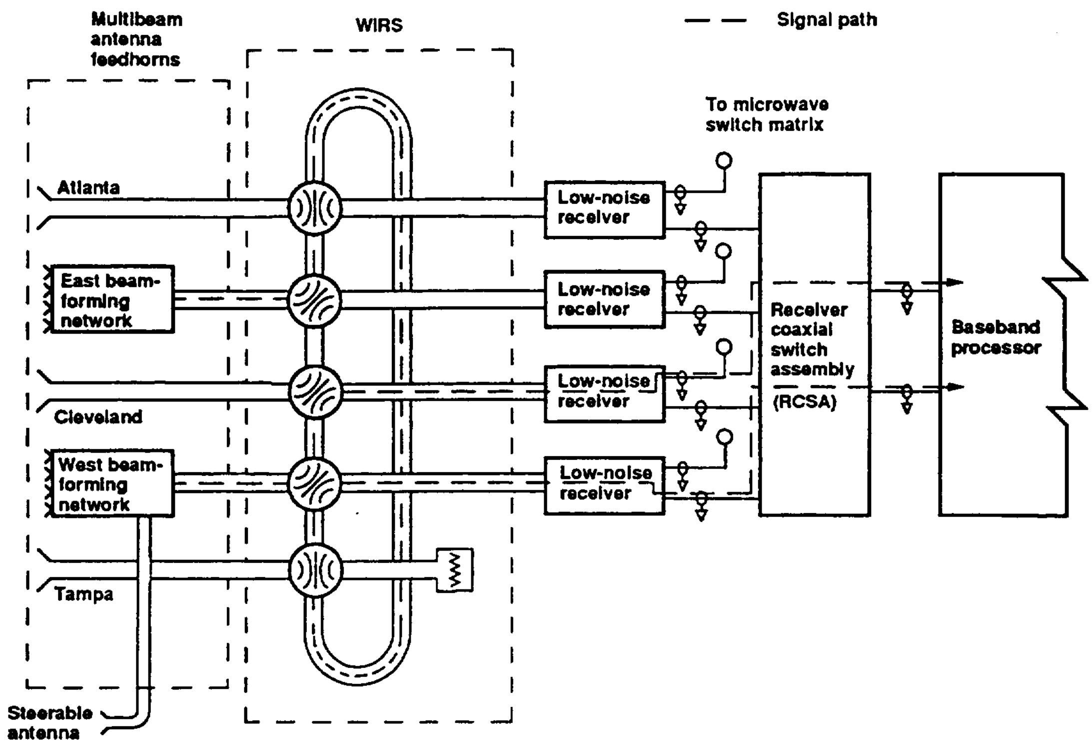
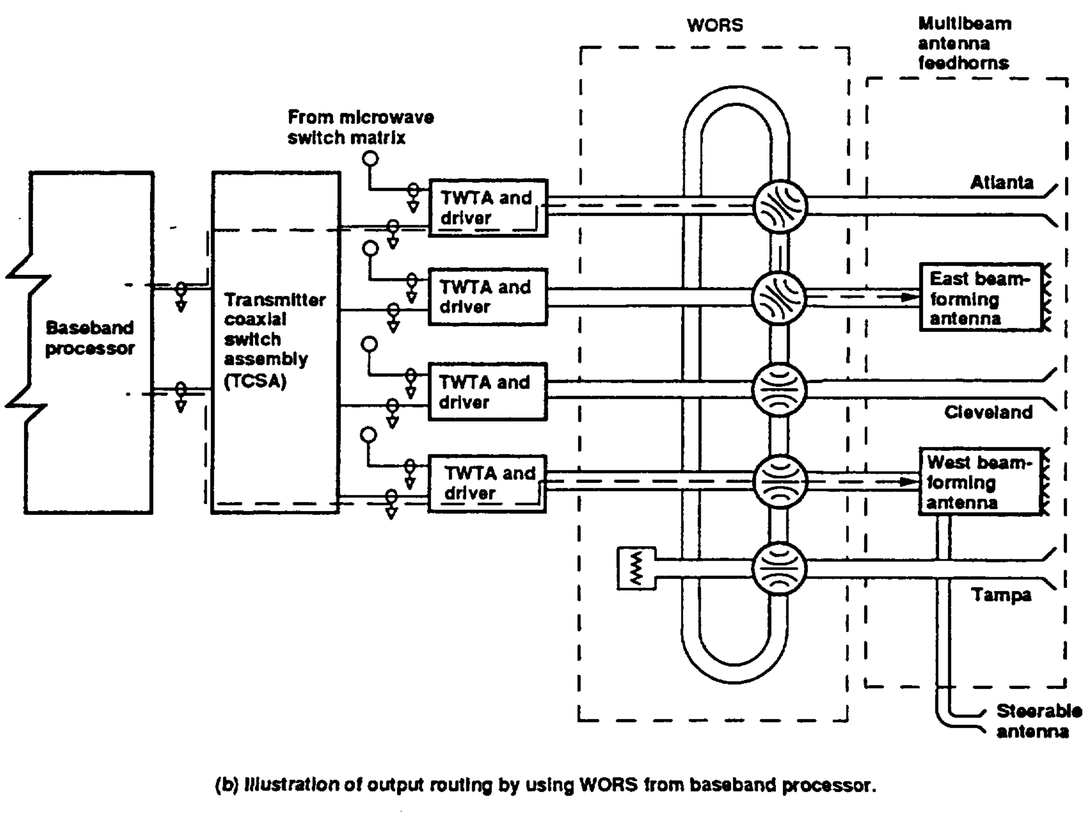


Figure B-4.—Spatial division using multibeam antenna.

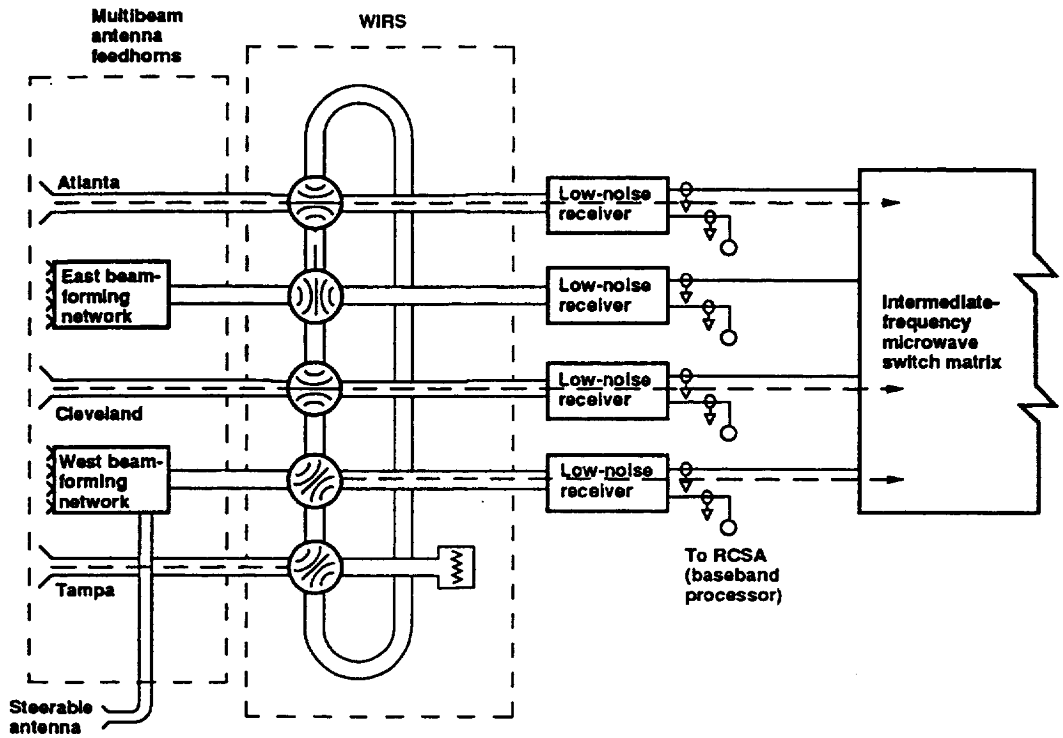


(a) Illustration of input routing by using WIRS to baseband processor.

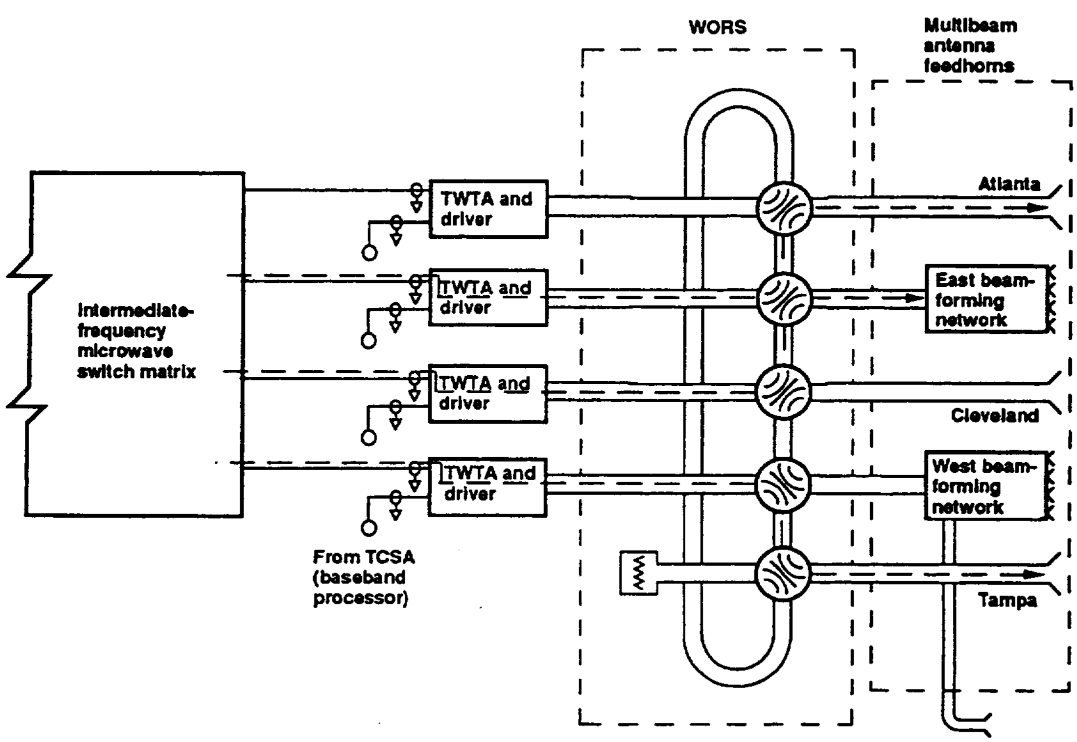


(b) Illustration of output routing by using WORS from baseband processor.

Figure B-5. — Examples of signal routing through waveguide input and output redundancy switches (WIRS and WORS).



(c) Illustration of input routing by using WIRS to microwave switch matrix.



(d) Illustration of output routing by using WORS from microwave switch matrix.

Figure B-5. — Concluded.

The transmitting and receiving antennas consist of three major components:

(1) The main reflectors
(2) The polarizing subreflectors
(3) The feedhorn networks

Figure A-3 locates these components on the spacecraft.

The transmitting and receiving main reflectors and their corresponding subreflectors are common to the transmitting and receiving feedhorn networks, respectively. The subreflectors are schematically shown in figure B-6. The transmitted and received signals are linearly polarized. Cross-polarization is used to improve isolation between adjacent sectors or spots and thus separate the adjacent beams. For linearly polarized waves a linear grid will reflect those waves with an electric field parallel to the direction of the grid lines and will transmit those perpendicular to the lines. Thus, the front subreflector is gridded and is focused on one feedhorn network, and the rear subreflector is focused on the other feedhorn network for a common main reflector.

The feedhorn networks are physically divided into four clusters of feedhorns as shown in figure B-7, a closeup view of the satellite. (Only three clusters are visible.) Each cluster contains one or two fixed horns, depending on the polarization of the cluster, and a beam-forming network. The beam-forming networks are also composed of feedhorn clusters. Figure B-8 shows an example of a beam-forming network and its waveguide circuitry. The use of a simple analogy will clarify the interaction of the feedhorn clusters with points on the ground. The reflectors and subreflectors act much the same as a camera lens (fig. B-9). The images of the feedhorns are focused by the lens to corresponding spots on the ground. By turning a particular set of feedhorns, information is sent to or received from that spot on the ground.

Referring back to figure B-5, note that the fixed-beam horns designated by Tampa, Cleveland, and Atlanta are connected directly to the waveguide redundancy (baseball) switches. These horns are not switched in the antenna network during the performance of an experiment because of the relatively slow switching speed (milliseconds) of the baseball switches. The switching of these antennas will be more clearly explained in the description of the microwave switch matrix mode of operation. The "high speed" switching part of the networks is in the beam-forming network, which is discussed in more detail next.

Figure B-10(a) is a schematic of the east receiving family of the beam-forming network. The term "family" is used because there are isolated locations outside of the hopping-beam scan sectors that cannot be called east locations. The common factor in each of the families is that horns contained in the same cluster have the same polarization. Starting where the beam-forming network connects to the baseball switch and working toward the horns, the first switch selects either the group of isolated spots or the scan array. Initially, assume that the scanning electronics selects a city covered by one of the isolated spots, such as Los Angeles. Each of the locations is covered by a single feedhorn and is located in the "picture" corresponding to a particular city. As determined by the scanning electronics, the remaining circulator switches are set to receive from Los Angeles. The time period for which the antenna "looks" at a particular area is called a dwell. The significance of

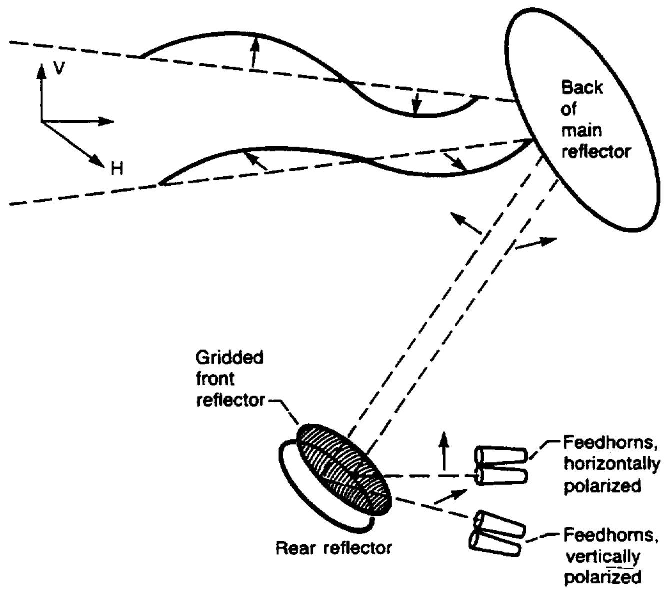


Figure B-6.—Schematic of polarizing subreflectors.

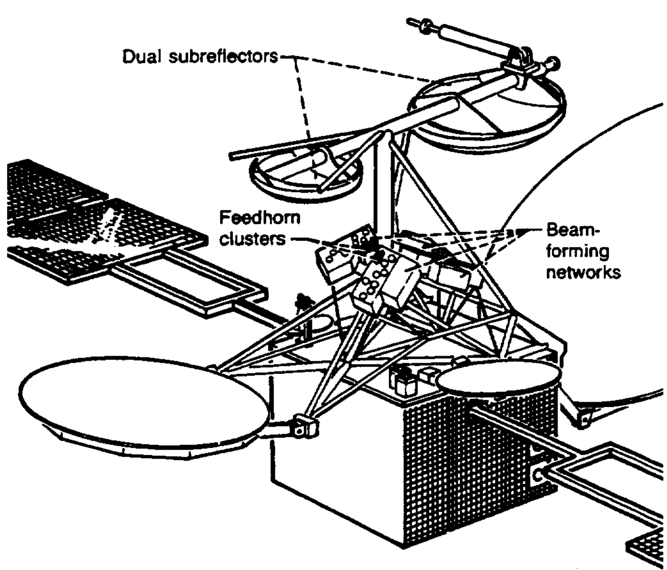


Figure B-7.—Closeup of feedhorn clusters.

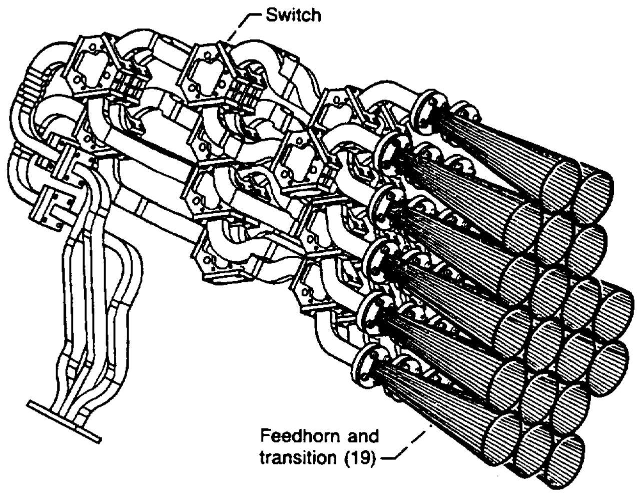


Figure B–8.—View of part of beam-forming network circuit.

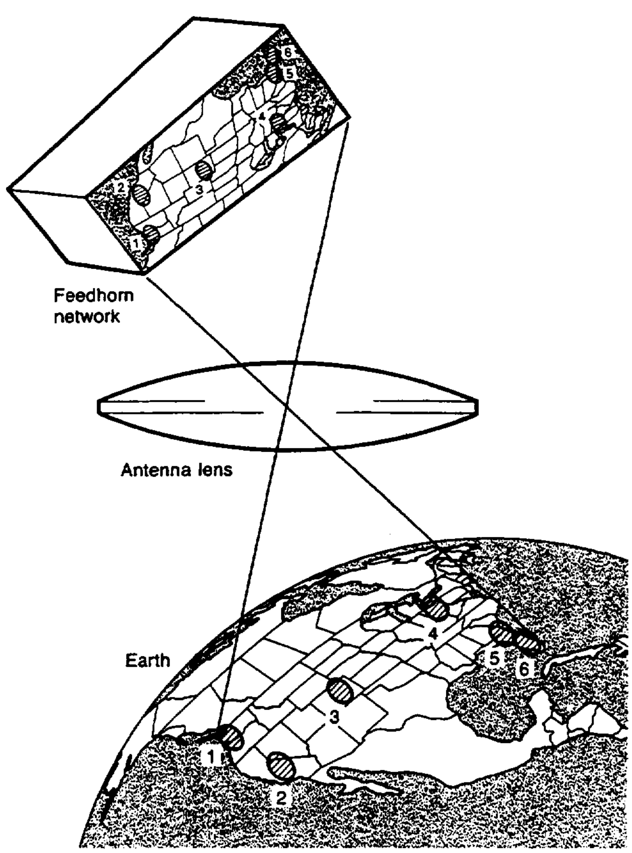
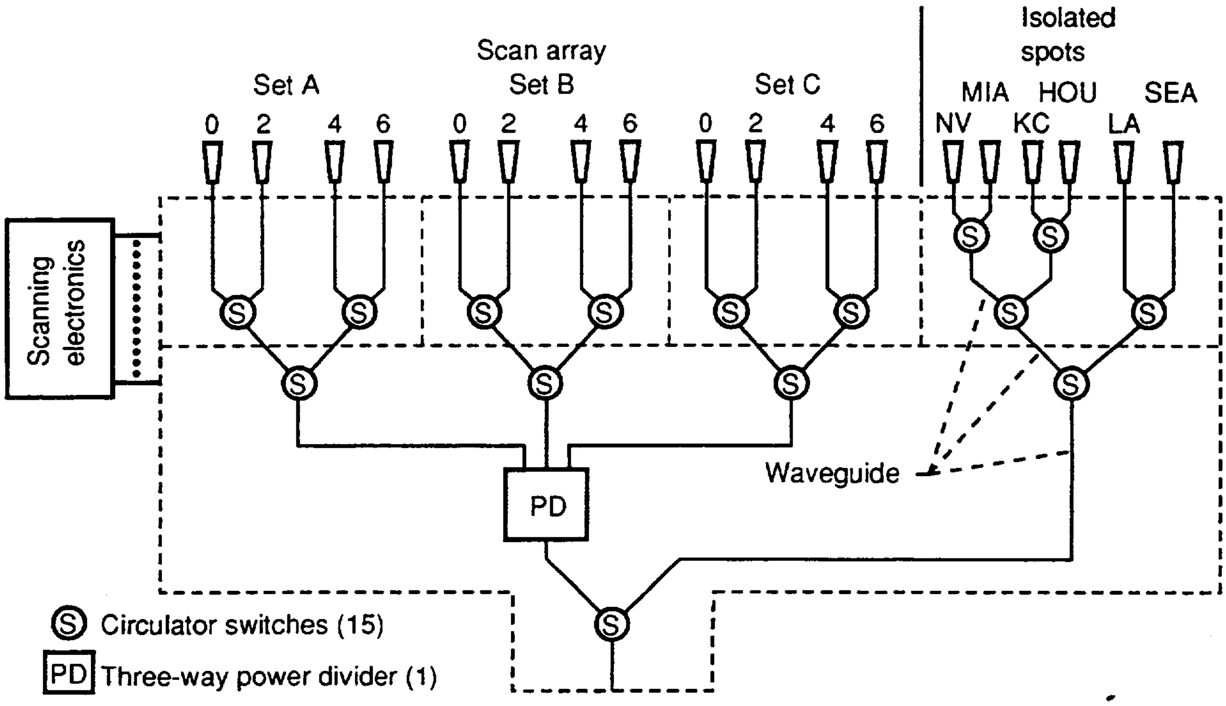
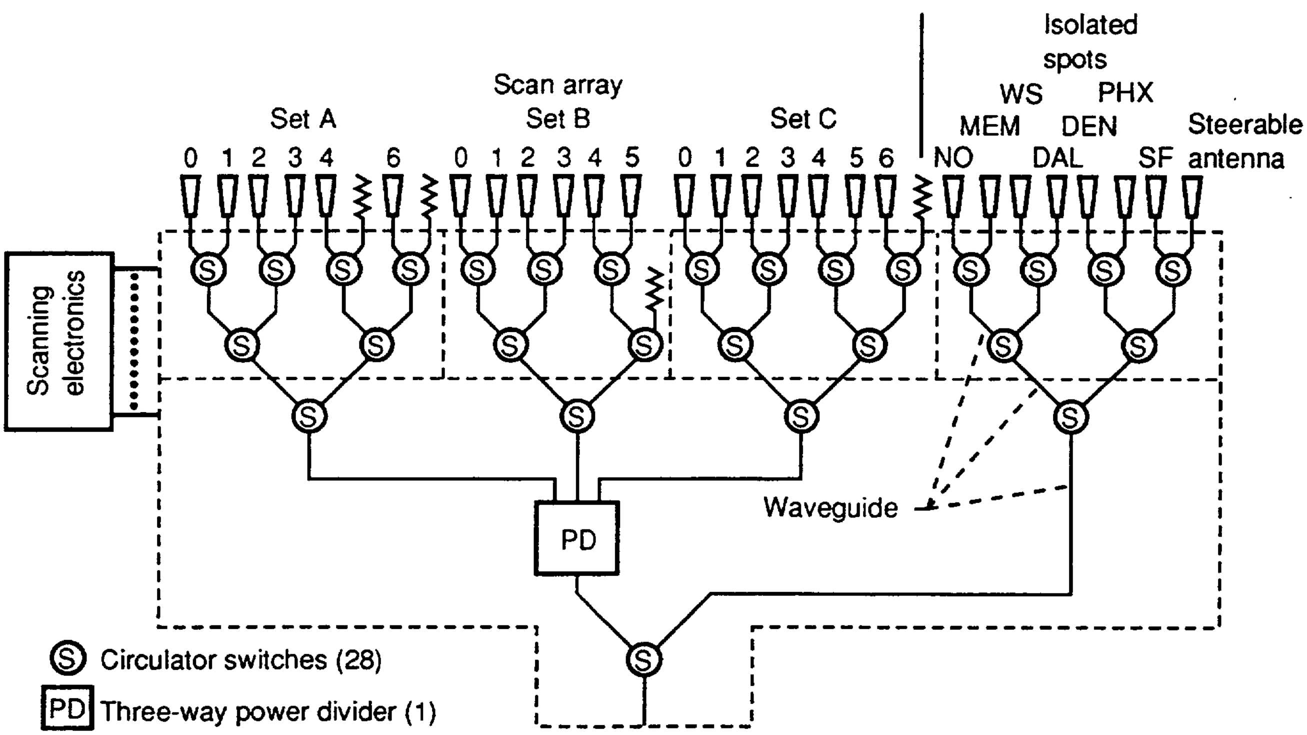


Figure B–9.—Multibeam antenna "camera."



(a) East scan array.



(b) West scan array.

Figure B–10.—Waveguide circuit configuration of receiving beam-forming networks.

the dwell will become apparent later in explanations of the baseband processor and the microwave switch matrix modes of operation.

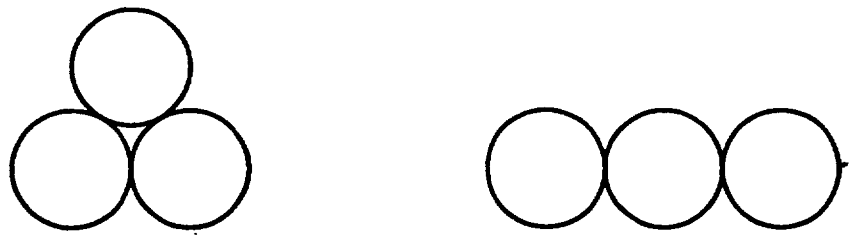
The operation of the scan array in the beam-forming network is not as easily visualized as the isolated spots in that there is no one feedhorn that defines a location in the image plane of our "camera." Suffice it to say that, unlike dealing with a real photographic image, the fact that ACTS "light" is in the radiofrequency region of the spectrum gives the ground spots fuzzy edges. This results in a "smearing" that causes two or three feedhorns touching each other to look like a single antenna feed. This idea is important to remember because the first element in the network past the first circulator switch is a three-way power divider. In other words, the spots in the scan area are being "looked" at with three feedhorns simultaneously. A programming constraint on the scanning electronics is that the feedhorns selected must be touching each other. Originally, this was confined to triangular patterns as illustrated in figure B-11(a). For better coverage in certain areas of the scan sector, linear patterns as depicted in figure B-11(b) were added to allowable configurations. Thus, in a similar fashion as for the isolated spots, the receiver can be programmed to "look" at a specific area on the ground.

There are four clusters containing beam-forming networks. The west receiving family operates in the same manner as the east receiving family. The east and west transmitting families illuminate the ground spots in the same manner as the receiving families look at the ground. Also, the receiving and transmitting antennas cover the same areas. Each network is independently programmable. As illustrated in figure B-12 the multibeam antenna can simultaneously receive from the east and west receiving families and transmit through the east and west transmitting families by using the beam-forming network. It is important to recognize that the four clusters can cover four different areas on the ground simultaneously.

As shown in figure B-10(b) the west family of the beam-forming network has, in addition to isolated-city spots, a steerable beam antenna connected to it. Although it is connected to the beam-forming network, the steerable antenna is a separate antenna. It can be pointed to any location in the United States, including Alaska and Hawaii. It is operated as part of the beam-forming network but has certain limitations. It is possible to receive and transmit simultaneously through the steerable antenna but, because it is a single antenna, it can access only one ground location at a time. Also, the smaller physical size of its main reflector, compared with the multibeam antenna reflectors, results in lower gain as well.

Low-Noise Amplifiers and Downconverters

The downconverters provide the low-noise amplification and frequency conversion of the received signals to a microwave intermediate frequency as shown in figure B-13. Intermediate-frequency signals are amplified further before they are routed to either the baseband processor or the microwave switch matrix by the intermediate-frequency modules. The downconverters operate in the radiofrequency input frequency range of 28.9 to 30.0 GHz and produce corresponding intermediate frequency output from 3.00 to 4.06 GHz by mixing the received signal with a local oscillator signal at 25.992 GHz. The local oscillator signal is coherent with all other reference signals within the multibeam communications package and is produced by direct multiplications of the 5-MHz



(a) Triangular. (b) Linear.

Figure B–11.—Feedhorn triplet patterns allowable in beam-forming network.

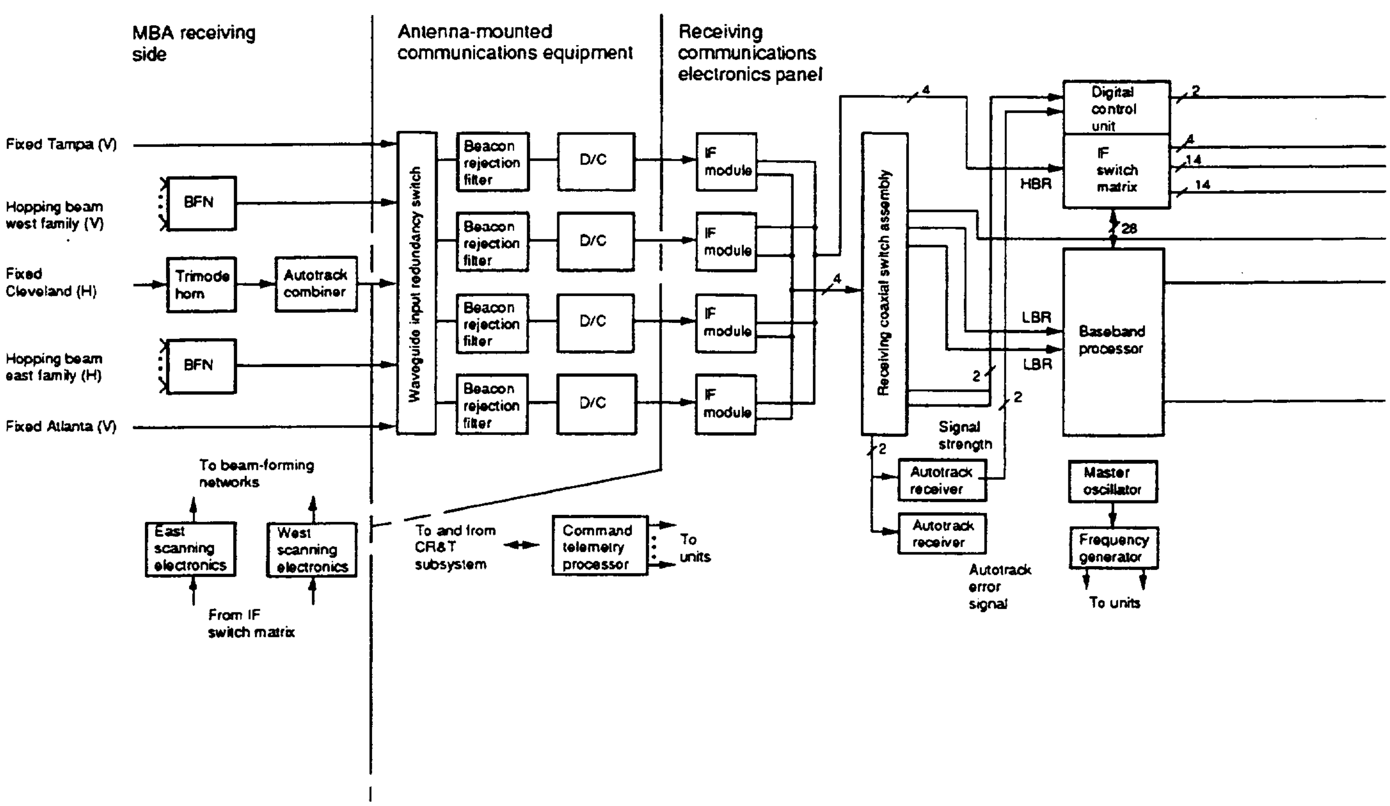


Figure B–13. —Major elements of

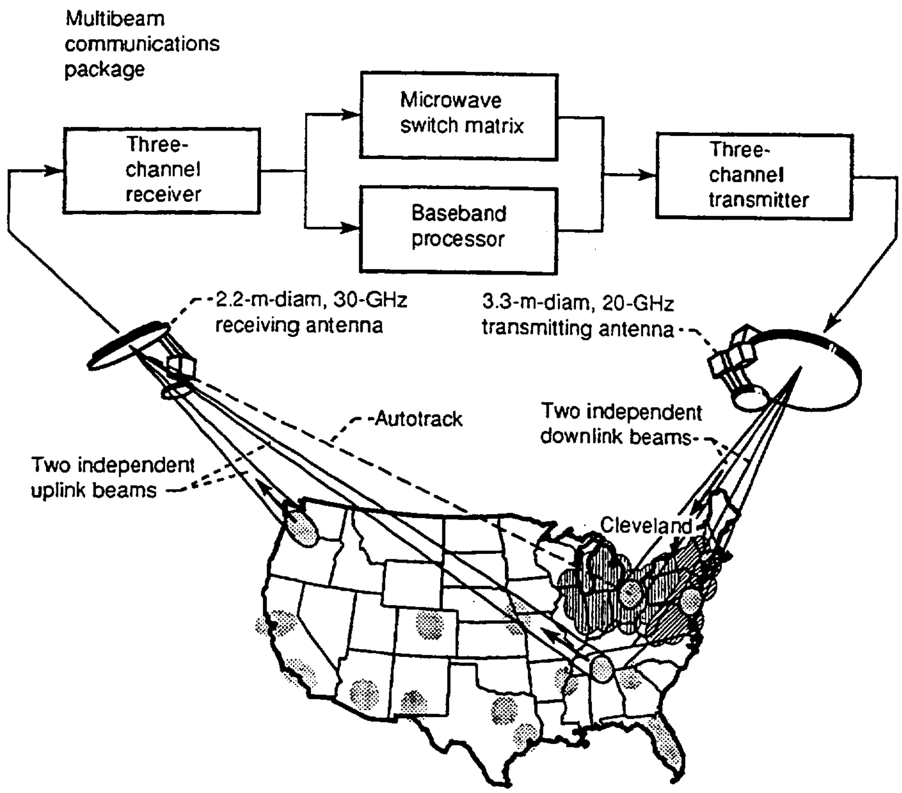
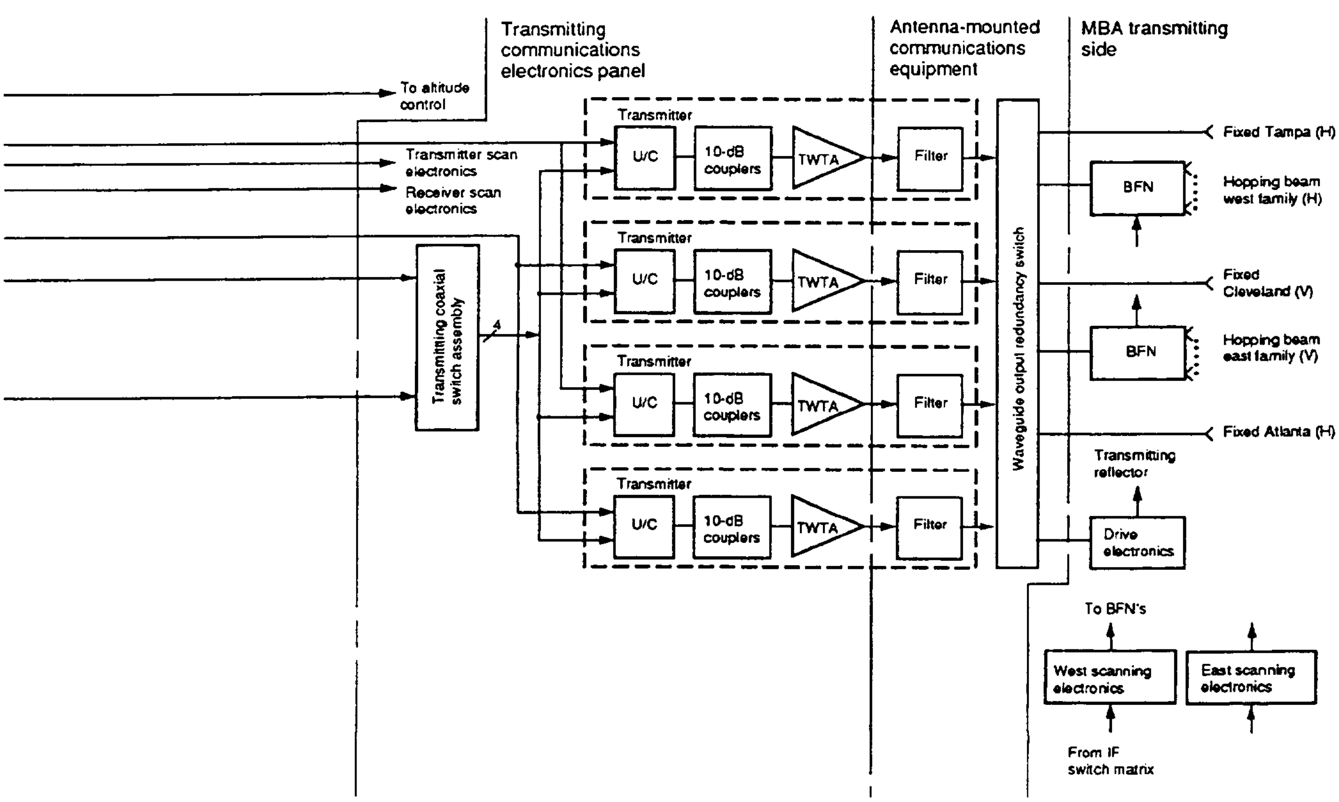


Figure B-12.—Simultaneous and independent coverage by multibeam antenna.



multibeam communications package.

master oscillator clock. Special inversion does not occur in any of the conversion processes. High electron mobility transistor devices are used in the downconverters to achieve low-noise amplification at the Ka-band frequencies (table B-1).

TABLE B-1. - CHARACTERISTICS OF LOW-NOISE RECEIVERS

Input frequency range, GHz	29.0-30.06
Noise figure, dB	5 max.
Gain, dB	40
Gain variation, dB	±0.5
Output frequency range, GHz	3.00-4.06

The intermediate-frequency modules accept the 3.00- to 4.06-GHz outputs of the downconverters and perform three functions: Baseband-processor-mode signals receive small signal amplification for interface with the baseband processor; microwave-switch-matrix-mode signals receive high-gain, hard-limited amplification; and autotrack receiver signals receive amplification. The autotrack receiver downconverts to 75 MHz for further processing. The signals for the autotrack function and the baseband-processor-mode signals are coupled from the primary signal path and have separate outputs. In effect, the intermediate-frequency module accepts a single wideband input and connects the three signal types to their corresponding routes for processing or routing. The communications signals passing through the multibeam communications package follow one of two parallel systems: the baseband processor, or the microwave switch matrix. A description of the baseband processor follows.

Receiver Coaxial Switch Assembly

Baseband-processor-mode and autotrack signals and signal strength measurements are routed to the baseband processor, the autotrack receivers, and detector logarithmic amplifiers, respectively, by the receiver coaxial switch assembly. This function is not required to be dynamic, and it is implemented with conventional mechanical switches at switching times of 200 msec or less.

Baseband Processor

A simplified functional block diagram of the multibeam communications package (fig. B-14) shows its relationship to the baseband processor. The four receiver outputs can be routed either through the intermediate-frequency switch to downlink transmitters for the microwave-switch-matrix mode communications or through a coaxial switch that routes two of the four uplink signals into the baseband processor. The two baseband processor outputs are routed through a coaxial switch to selected downlink transmitters.

A functional block diagram of the baseband processor is shown in figure B-15. The ACTS baseband processor is a scaled-down configuration that maintains sufficient capability to demonstrate the baseband-switching technology. The major elements consist of two input channels, a three-by-three routing switch, and two output channels. The baseband processor supports a maximum throughput of 220 Mbps.

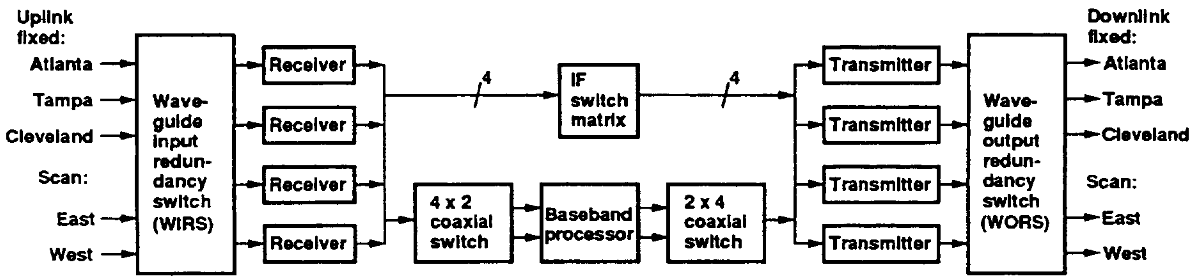


Figure B-14. —Simplified functional block diagram of multibeam communications package.

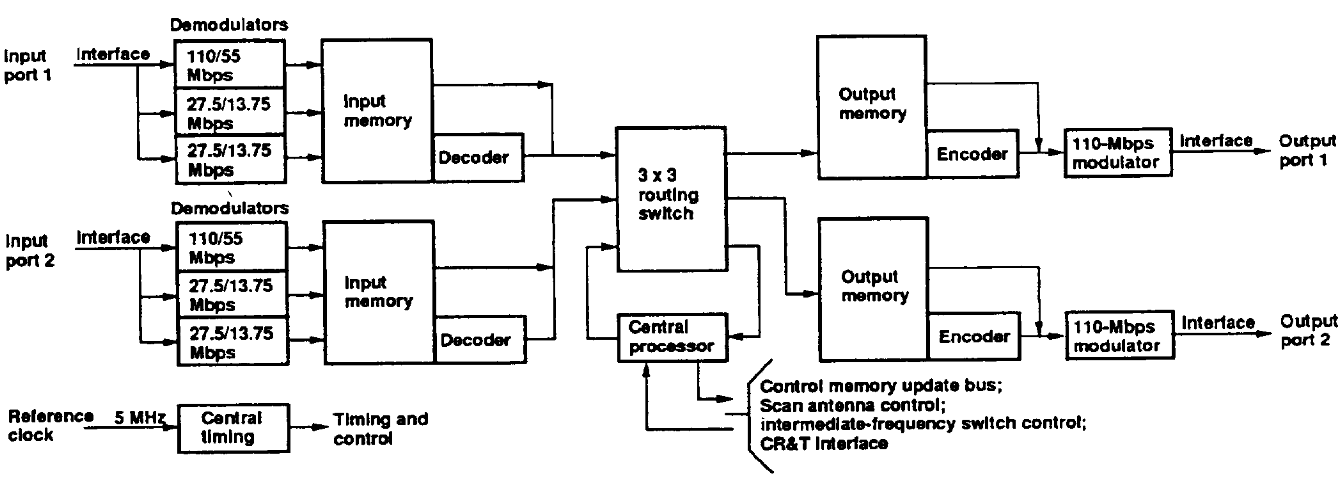


Figure B-15. — Functional block diagram of baseband processor.

Each input channel contains three dual-rate, SMSK demodulators, an input memory, and decoders. The demodulators receive intermediate-frequency inputs consisting of SMSK-modulated intermediate-frequency bursts at approximately 3.2 GHz. Bursts are received by either a 110/55-Msps demodulator or by two 27.5/13.75-Msps demodulators. Bursts received by the 110/55-Msps demodulator occur uniquely in time relative to bursts received by the two 27.5/13.75-Msps demodulators, with the higher rate demodulator sharing the frequency allocation with the two lower rate demodulators. The demodulator serial outputs are converted to 64-bit data words and stored in an input data memory. Each input memory has the capacity for storing a 1-msec frame of 110-Msps data. Coded messages are read from the input memory and shifted through parallel convolutional decoders.

The three-by-three routing switch receives 110-Msps serial data from the two input channels and the central processor. These data are switched to the two output channels and the central processor on a 64-bit-word basis. A control memory operating at a 110-divided-by-64-megawords-per-second rate provides the routing switch interconnect controls.

The output channels receive 110-Msps serial data from the routing switch and store the data in a manner similar to that used by the input memories. Downlink data formatting is provided by reading the output memory, which contains addresses programmed into a control memory. Downlink data not requiring coding bypass the encoder, but data requiring coding are serially encoded prior to modulation. Rate-1/2 encoding is performed at an input rate of 27.5 Mbps, producing an output symbol rate of 55 Msps. The uncoded downlink modulation rate is 110 Mbps.

A central processor performs various command, telemetry, and control functions for the baseband processor. A central timing module generates internal clocks coherent with a 5-MHz reference. The central processor, the central timing module, and the routing switch are totally redundant in the baseband processor.

In the event of certain failures the surviving equipment is utilized in a time-share mode to provide baseband communications among all the users in both hopping beams. For the uplink the time-share mode uses the intermediate-frequency switch matrix to route both hopping beam signals to the surviving baseband processor input. For the downlink surviving baseband processor output is applied simultaneously to the two hopping beam outputs.

Message formats. - A unique feature of the baseband processor is that the uplink and downlink multiplexing formats can be different. Uplink messages are carried as frequency-division multiplexed (FDM) signals with time-division multiple access (TDMA). The uplink beam organization is shown in figure B-16. The available communications space is divided into 1-msec timeframes during which the scanning antennas sequentially hop and dwell on spots within their geographically assigned sectors. During any one spot dwell time burst transmissions occur in an FDM/TDMA format. Within any one FDM channel a spot is divided into a sequence of individual terminal-burst transmissions. Uplink burst rates are 110 and 27.5 Mbps for uncoded traffic and 55 and 13.75 Mbps for coded traffic. Guard intervals are inserted between bursts to avoid message-processing collisions and between spots to allow for antenna switching.

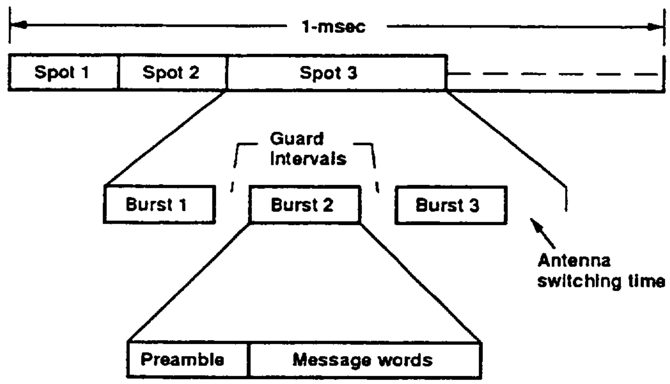


Figure B-16. — Uplink beam frequency-division-modulated TDMA organization.

Within any downlink spot, messages are transmitted in a pure time-division multiplexing (TDM) mode. During the 1-msec timeframe the individual downlink antennas hop and dwell on spots within their assigned sectors. However, during any one spot dwell time the downlink transmission is a single continuous burst. The beginning of a dwell contains a reference burst, which is followed by the uncoded 110-Msps traffic. The coded 55-Msps traffic is placed after the uncoded traffic in a pool. A receiving terminal within a downlink spot extracts its message on a TDM basis.

Message synchronization. - Each uplink burst transmission begins with a preamble to allow carrier acquisition and bit synchronization followed by the message. A 256-bit preamble is used for uncoded bursts. A 384-symbol preamble and a 64-bit postamble are used for coded bursts. A unique word at the end of the preamble establishes message word synchronization and word boundaries for storage. Each burst received at the baseband processor will have a tracking error word generated. The baseband processor generates the tracking error word by observing the uncoded word portion of the preamble and correlating it with a stored word to determine whether the burst is early or late. The tracking error word is a 64-bit sequence with the format shown in table B-2.

TABLE B-2. - TRACKING ERROR WORD FORMATS

Timing of received burst	Tracking error word format			
	Most significant bit			Least significant bit
Late	F 0 F 0	F 0 A 5	F 0 F 0	F 0 A 5
Early	F 0 F 0	F 0 5 A	F 0 F 0	F 0 5 A
No lock	F 0 F 0	F 0 F 0	F 0 F 0	F 0 F 0

A burst that arrives before the assigned arrival time will result in an early tracking error word being generated and stored in the input memory in the position that would have been occupied by the last word of the preamble if it had been stored. The master control station must program the baseband processor routing to ensure that the correct tracking error word is provided to all users on the downlink so that they can maintain synchronism. A burst arriving late will receive a late tracking error word. There is no indication for an on-time burst. If the demodulator fails to recognize the uncoded word in the window defined in table B-3, the no-lock tracking error word is generated. The early/late code represents the case in which the apparent burst arrival time is early (or late) by as much as the times indicated in table B-3.

TABLE B-3. - RANGE FOR TRACKING ERROR WORD GENERATION

Mode	Early range	Late range
WH[a]	62.3 nsec (min.)	81 nsec (min.)
NH[b]	62.3 nsec (min.)	108 nsec (min.)
WL[c]	Two data bit times (~72 nsec)	Three data bit times (~109 nsec)
NL[d]	Two data bit times (~289 nsec)	Three data bit times (~434 nsec)

[a]Wideband, high rate.
[b]Narrowband, high rate.
[c]Wideband, low rate.
[d]Narrowband, low rate.

The ranges over which the baseband processor will store the data correctly are indicated in table B-4.

TABLE B-4.—RANGE FOR CORRECT DATA STORAGE

Mode	Early range	Late range
WH[a]	65 nsec	73.5 nsec
NH[b]	65 nsec	73.5 nsec
WL[c]	Two data bit times (~72 nsec)	Three data bit times (108 nsec min.)
NL[d]	Two data bit time (~289 nsec)	Three data bit times (~434 nsec)

[a]Wideband, high rate.
[b]Narrowband, high rate.
[c]Wideband, low rate.
[d]Narrowband, low rate.

For the uncoded modes the ranges for correct storage are slightly different from the tracking-error-word range. Considering the limits for both tracking-error-word generation and data storage, the following can occur:

(1) First, from 62.3 nsec early to 73.5 nsec late, proper data storage and early/late tracking-error-word generation occur.

(2) From 73.5 to 81 nsec late for the high rate and to 108 nsec late for the low rate, a late tracking error word will be generated, but the data may not be stored correctly.

(3) Of little importance is the case from 65 nsec to the tracking-error-word early range limit where data may be stored correctly but a no-lock tracking error word will be generated. The ground station will just retransmit the burst.

Note that the baseband processor's required performance range is ±60 nsec; both the tracking-error-word and storage ranges are consistent with this requirement.

For coded modes the tracking error word is generated from the decoded signal, since the unique word is coded. Thus, the ranges for storage and tracking-error-word generation are the same. The wider windows for coded bursts apply in the acquisition case, since acquisition is always done in the coded mode. After the TDMA burst controller completes acquisition, the burst timing will be well within the ±60-nsec limit so that the switch to uncoded operation may be accomplished readily.

Coded bursts that arrive outside the window will result in storage of partial or garbled message words. These will be presented for decoding, and the decoder output will be presented to the correlator. There will be a significant number of spurious early or late indications among the no-lock indications because of the finite length (seven bits) of the uncoded word sequence.

The nominal arrival time for a coded burst is different from that for an uncoded burst, and there is a tolerance to cover the uncertainty in this difference over the life of the spacecraft, temperature variations, etc. The arrival time differences are as follows:

(1) Between modes WH and WL: 66 ± 6 nsec
(2) Between modes NH and NL: A demodulators (channel 6), 261±7 nsec
B demodulators (channel 7), 264.8±7 nsec

In going from uncoded (H) mode to coded (L) mode the transmitter timing in the Earth terminal is advanced by the amount shown, and conversely for the opposite transition.

ACTS custom large-scale integrated circuits. - A family of custom large-scale integrated circuits was developed for the ACTS Program. The nine circuit types are listed in table B-5.

TABLE B-5.–FUNCTIONS OF LARGE-SCALE INTEGRATED CIRCUITS

Type	Quantity	Function	Technology
1	4	Maximum-likelihood convolutional decoder	Complementary metal oxide semiconductor
2	24	Memory-updated controller	
3	28	Serial to parallel/ parallel to serial	
4	2	Encoder	Motorola oxide self-aligned implanted circuits (MOSAIC) using emitter-coupled logic[a]
5	6	Serial to parallel	MOSAIC using open-collector-current-mode logic
6	32	Parallel to serial	
7	6	Correlator	
8	4	Timing and control A	
9	4	Timing and control B	

[a]A custom 10 x 10 cell array was developed for the MOSAIC devices.

SMSK demodulator. - Two dual-rate SMSK demodulator designs support the 110/55-Msps and 27.5/13.75-Mbps uplink data rates. Both use a common design approach as shown in figure B-17. A composite intermediate frequency is received into a bandpass filter to limit adjacent channel interference. A variable-gain feedback control provides a constant-amplitude signal into the carrier tracking loop.

Each uplink burst is acquired separately. The data pattern at the start of the uplink preamble assists the carrier tracking loop in acquiring the carrier frequency. The preamble also provides for a rapid acquisition of the clock loop. A data pattern injected into the clock loop pulls it to the correct frequency and phase. Clock injection is activated on the falling edge of a synchronization gate signal programmed into the demodulator control memory. During no-message periods a reference oscillator is switched into the loop to maintain the clock loop frequency.

The demodulator outputs are tied to an input memory assembly. Sign and magnitude data outputs are provided for two-bit soft decisions with the decoders. A synchronization signal identifies coded symbol pair boundaries and helps establish a correlation window for uncoded data.

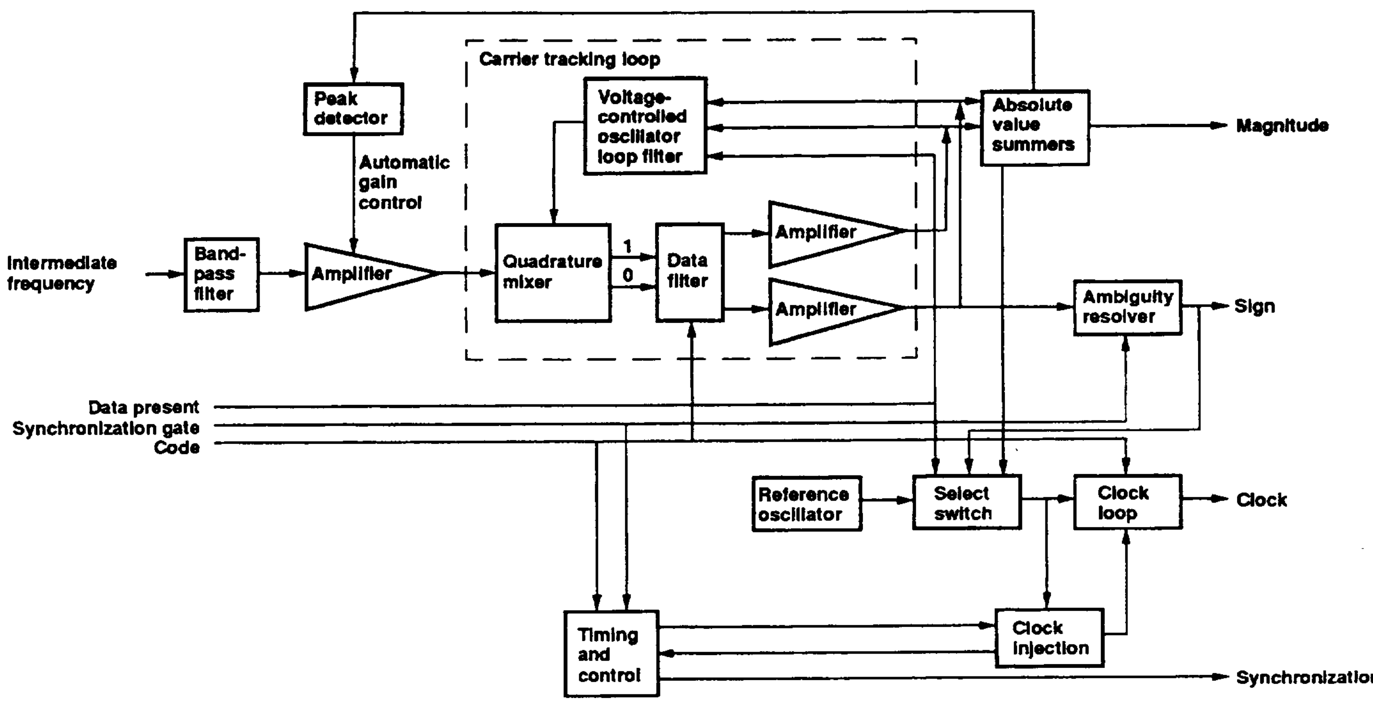


Figure B-17. — Functional block diagram of SMSK demodulator.

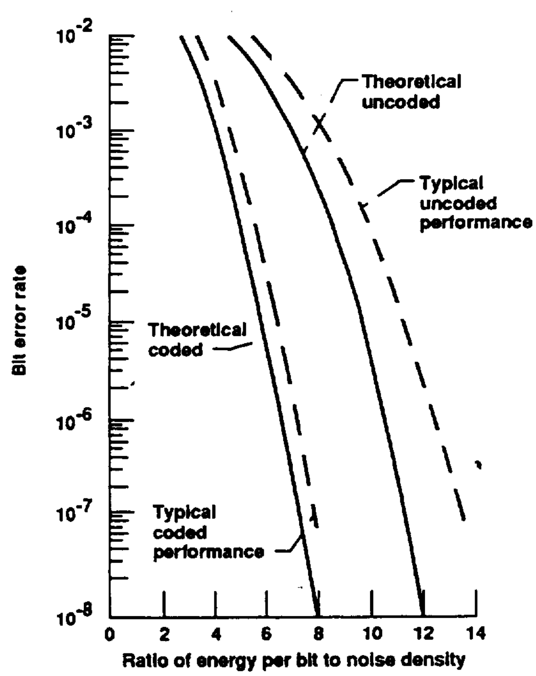


Figure B-18. — Coded and uncoded bit-error rate performance.

Forward-error-correction decoding. - Convolutional decoding that utilizes maximum-likelihood techniques is used in the ACTS baseband processor to provide forward error correction for offsetting signal degradation caused by rain. A maximum-likelihood-convolutional-decoder, large-scale integrated circuit was developed for the ACTS Program. Its implementation is a single-chip CMOS design that uses a coding rate of 1/2, a constraint length of 5, and a two-bit soft decision and path memory length of 28. The maximum-likelihood convolutional decoder provides over 4 dB of link improvement at a bit error rate of 10^{-6} relative to uncoded messages, as shown in figure B-18. Coding rate 1/2 coupled with a symbol rate reduction of one-half provides an additional 6 dB of gain for a total improvement by forward error correction greater than 10 dB.

Sign and magnitude elements are generated by the demodulators from the coded symbols received and stored into the input memory. A coded word is read from the input memory at intervals of 16 word times and loaded into parallel-to-serial converters for shifting through the decoders. Because of the decoder chip speed, parallel maximum-likelihood-convolutional-decoder chips are used to provide a total decoding throughput of 6.8 Mbps per channel. Odd and even coded symbol pairs are multiplexed into the parallel decoders as shown in figure B-19. Each decoder receives a sign and magnitude serial stream at 6.8 Mbps, generating a decoded output of 3.4 Mbps. The decoder outputs are multiplexed.

Memory architecture. - The memory architecture shown in figure B-20 is used for both the input and output memories. This memory architecture provides a continuous store and forward function with a 110-Mbps throughput. During each frame data are written into one data memory while the previous frame of data is read from the other. Data memories alternate read and write functions in each frame.

The input and output memories receive high-speed serial data from demodulator outputs and routing switch outputs, respectively. Custom serial-to-parallel-converter, large-scale integrated circuits convert the high-speed serial data into 64-bit words for storage into CMOS data memories. An incrementing counter provides sequential addresses for write operations, and a control memory provides programmable addresses for read operations.

Control memories. - Control memories in the baseband processor direct data routing and control functions on a word-time basis repetitively each frame. All control memories are 2K deep, allowing mapping of a full frame of 110-Mbps data on a 64-bit-word basis. Control memories in the input channel generate control signals required by the demodulators for message acquisition, addresses for reading data memories, and control signals for decoding coded data. A routing-switch control memory controls interconnections through the three-by-three routing switch and directs the routing of the central processor command and status words. Control memories in the output channels provide read addresses and control signals for encoding.

Control memories are grouped in pairs such that one memory can actively control while the other is available to be programmed for new routing configurations. Control-memory update information is received from either the baseband processor uplink or the CR&T link. It is then processed by the central memory interfaces with the central processor through a memory-update-controller, custom, large-scale integrated circuit. Memory-update controllers armed with data then transfer the data to their respective control memories during the last six 110-Mbps/64-word times at the end of a frame.

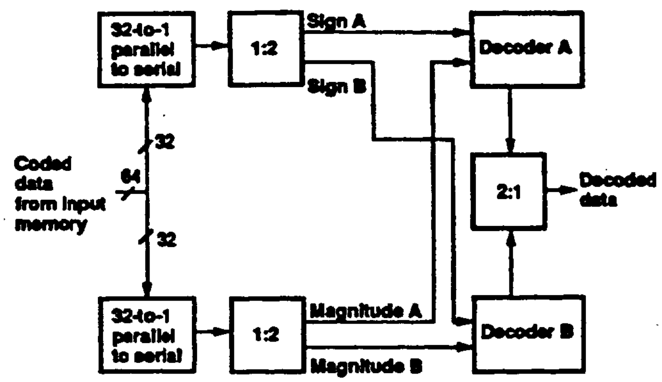


Figure B-19. — Configuration of input channel decoder.

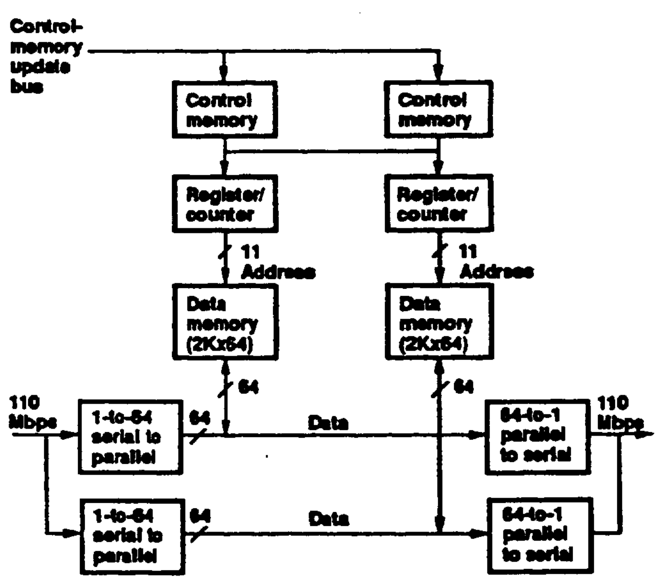


Figure B-20. — Memory architecture.

Central processor. - The central processor provides the means by which the master control station reconfigures routing through the baseband processor for changing traffic. A microprocessor architecture as shown in figure B-21 controls the necessary interfaces. An SBR9000, 16-bit microprocessor is used with 8K words of read-only memory and 2K words of random-access memory. Interfaces are provided for baseband processor commands and status, CR&T commands and status, scan antenna controls, and control-memory updates.

The central processor receives, verifies, and distributes control-memory update commands. Control-memory updates are normally received via the baseband processor uplink and are sent to the central processor through the routing switch. The CR&T link can also be used as a backup to transmit commands at a slower rate. Commands are verified prior to execution by using an eight-bit checksum and instruction parity. Valid commands are shifted out to the corresponding control-memory update controller, where they are executed at the end of the frame.

Status information is reported to the master control station by the central processor. Status information is available via the routing switch to the baseband processor downlink and the CR&T link. Each update command generates a corresponding command status word. Parity errors detected in active control memories are also reported.

A modulo-75 frame counter is maintained by the central processor to indicate superframe boundaries. Control-memory swap commands are executed at the superframe boundaries to allow inactive control memories that have been reconfigured to be swapped with active ones in a sequential fashion such that no data are lost through the baseband processor.

The central processor also supports four modes of operation: initialization, acquisition, normal, and self-test. Initialization can be entered as the result of powerup or by command. The initialization mode performs a self-test, initializes the superframe counter, and configures the baseband processor to receive and transmit predetermined acquisition bursts. The acquisition mode is entered at the completion of initialization or by command. The acquisition mode supports uplink and downlink signal synchronization with the NASA ground station. The normal mode is entered by command and supports normal baseband processor traffic. A self-test mode can be entered by command to verify the central processor operation. Uplink and downlink scan antenna controls are also provided by control memories in the central processor.

Transmitter Coaxial Switch Assembly

The transmitter coaxial switch assembly, which is similar in function to the receiver switch assembly, routes the outputs of the baseband processor to the desired upconverter and power amplifier chain. It is also a mechanical switch unit with switching times of 200 msec or less.

Microwave Switch Matrix

Microwave-switch-matrix-mode signals from the intermediate-frequency modules are routed to the microwave switch matrix. This assembly is constructed

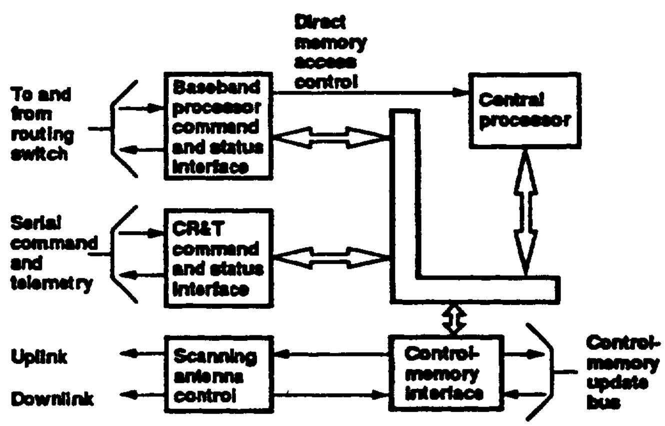


Figure B-21. — Block diagram of baseband processor's central processor.

of a four-by-four switch matrix with crossbar architecture. The switch configuration is controlled by ground commands programmed into the multibeam communications package's digital command unit. Switch crosspoints consist of two field-effect-transistor pairs, where one device per pair provides the switching function with a switch state duration of as little as 1 μsec and can switch in less than 100 nsec. The intermediate-frequency switch assembly allows any input port to be interconnected with any output port, including a broadcast mode in which a single input can be connected to as many as three output ports. The system function of the microwave switch matrix is to route a received uplink signal from one beam to the desired downlink beam or beams. It does not interact with the baseband-processor-mode signals. However, the switch can access the spot beams that are usually carrying baseband-processor-mode signals and can route microwave-switch-matrix-mode signals through these beams. In this mode baseband-processor-mode signals would not be present at the input to the multibeam communications package.

Upconverter and Traveling-Wave Tube Amplifiers

Baseband-processor-mode signals from the onboard modulation and microwave-switch-matrix-mode signals from the microwave switch matrix are provided as inputs to the upconverter and the high-power amplifiers. Inputs in the 3.00- to 4.06-GHz intermediate frequencies are upconverted by mixing the signals with a local oscillator signal at 16.2 GHz. Solid-state amplifiers in the upconverter assemblies provide the necessary drive level for the TWTA high-power amplifiers. TWTA outputs are connected to the transmitting antenna via a redundancy switch network.

Downlink Upconverter Spurious Signals

During alignment and testing of the flight downlink signal upconverters at Martin Marietta Astro-Space, unexpected spurious output signals were discovered that were not present on the engineering model unit. These spurious signals, which became evident after a design change, appear after the mixer (right side of fig. B.21A) where the 16.2 GHz local oscillator signal is mixed with the communications IF signals.

Some of the spurious signals exceeded the original design specification of -45 dBc. Because these spurious signals were detected late in the spacecraft's development, the most reasonable option was to relax the design specification, provided that their impact on existing operational concepts was acceptable. Therefore, the maximum level of the spurious signals has been changed to −30 dBc or less.

Three products of the spurious output signals were identified. Two of the spurious signals lie within the frequency band for baseband processor operations. All three spurious products lie within the 800-MHz microwave-switch-matrix-mode band, but only one lies within the frequency band used by the link evaluation terminal. The spurious products and their associated intermediate-frequency band are summarized as follows:

Product	IF frequency range	Mode(s) affected
$2F_{LO} - 4F_{IF}$	$3.05 \leq F_{IF} \leq 3.30$ GHz	BBP, MSM
$5F_{IF}$	$3.84 \leq F_{IF} \leq 4.04$ GHz	MSM
$6F_{IF}$	$3.20 \leq F_{IF} \leq 3.37$ GHz	BBP, MSM

Figure B-21B indicates the "danger zones" in the frequency spectrum where spurious signals will be present. A comparison is made to the IF ranges used for current ACTS experimenter terminals.

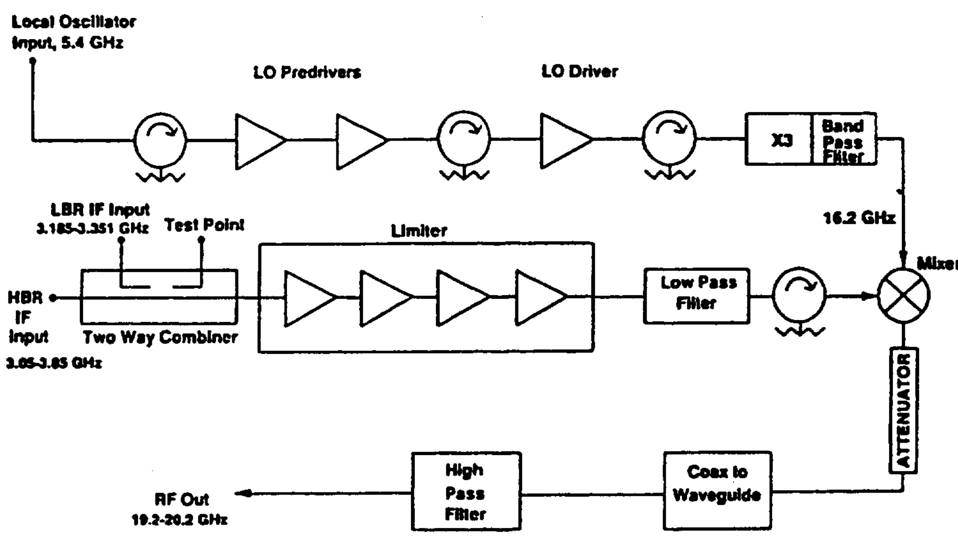


Figure B-21A.—Downlink upconverter block diagram.

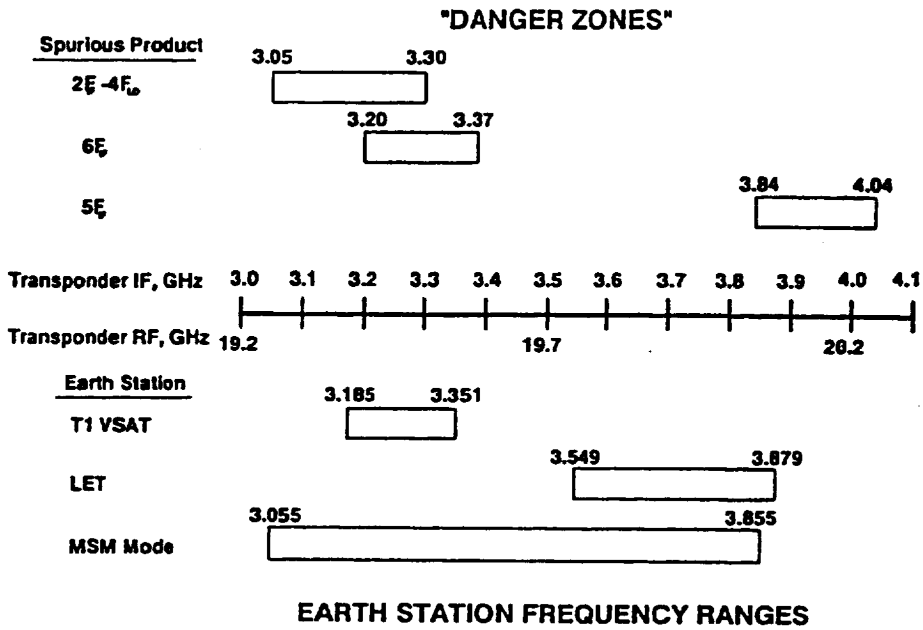


Figure B-21B.—Spurious signals frequency ranges.

Command, Ranging, and Telemetry

The CR&T subsystem provides the basic monitoring, ranging, and control functions for the ACTS spacecraft. It incorporates a Ka-band primary mode and a C-band mode for backup, transfer orbit, and drift orbit operations. Ka-band primary-mode operations are accomplished via the Ka-band equipment at the NASA ground station in Cleveland. For this purpose the NASA spacecraft-unique CR&T equipment is interconnected via land line to the Martin Marietta satellite control center in New Jersey. This configuration permits continuous control of flight systems when the NASA ground station is unmanned and obviates the need for a satellite control staff dedicated to the ACTS spacecraft.

Complete C-band backup is provided by CR&T equipment located at another Martin Marietta ground station. This CR&T facility contains a second complete complement of spacecraft-unique equipment that is also connected to the Martin Marietta satellite control center. Transfer and drift orbit operations are performed with the C-band system through the Martin Marietta C-band station in New Jersey and a second C-band station in Guam.

The spacecraft incorporates onboard autotracking equipment that monitors the Ka-band command carrier constantly being transmitted from the NASA ground station. The autotracking error signal is provided to the attitude control equipment for pointing corrections. Autotracking is not provided in the backup C-band mode. If the Ka-band command carrier is not transmitted, the spacecraft uses an Earth sensor for pointing determination. Single-station ranging is performed with the Ka-band CR&T equipment together with the autotrack system for on-orbit stationkeeping.

Figure B-22 depicts the basic elements of the CR&T subsystem.

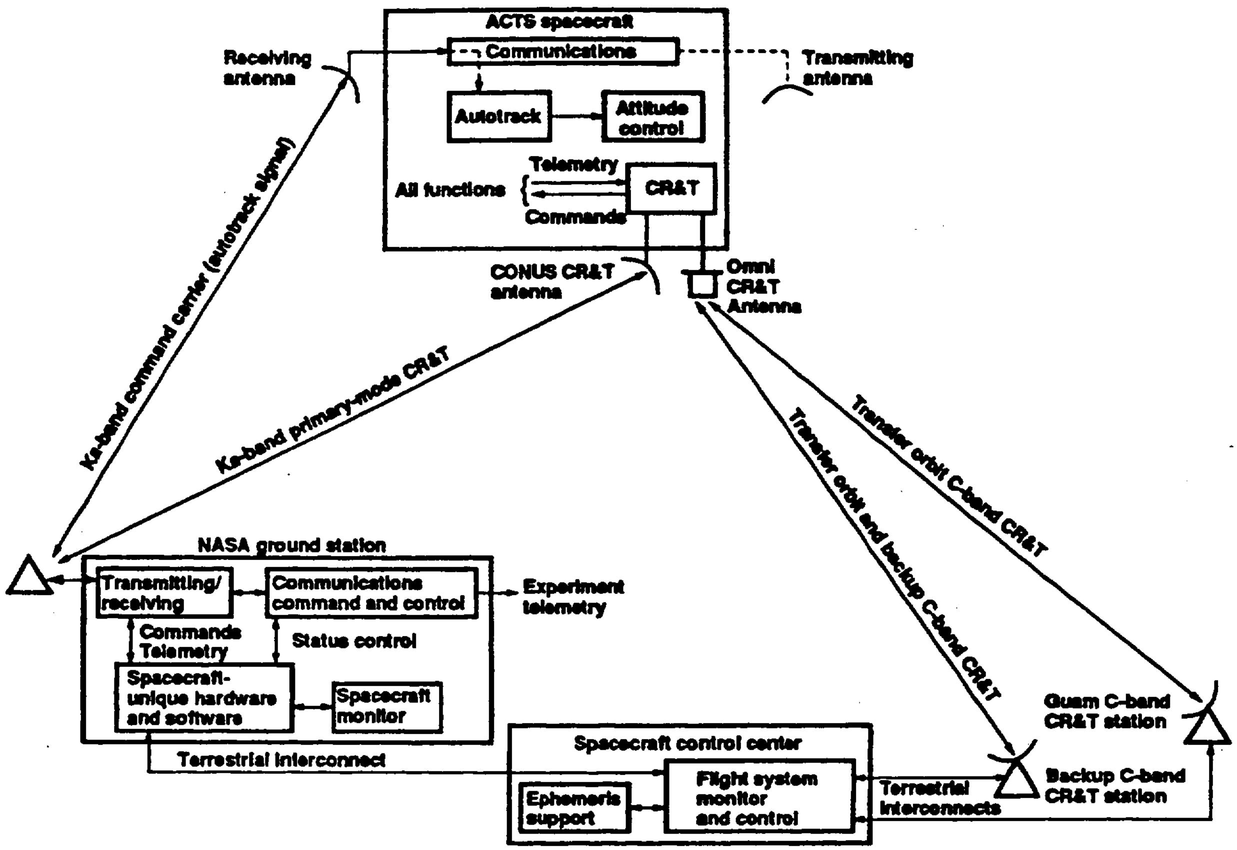


Figure B-22. — Functional configuration of CR&T and autotrack subsystems.

CR&T parameters of general interest are shown in table B-6. The values are nominal.

TABLE B-6. - GENERAL CHARACTERISTICS OF TELEMETRY AND RANGING

Telemetry beacon frequencies, GHz, and polarization:	
C band	3.7005 and 4.1995
Ka band	20.185 vertical; 20.195 horizontal
Beacon stability	1 part per 10^5
Beacon EIRP, dBW:	
C band	-2.8 (transfer and drift); -0.3 (on station)
Ka band	17.5 (CONUS coverage)
Beacon modulation (phase, 1 rad peak):	
Pulse-code modulated	1-kbps biphase-L on 32-kHz subcarrier
Analog	14.5-kHz subcarrier
Coverage	CONUS
Ranging tones (present on beacons periodically), Hz:	
Fine	27 779
Intermediate	3968
Coarse	293.45
Ranging tone modulation index	1 rad peak

Stationkeeping and Tracking Equipment on Spacecraft

To maintain the required pointing accuracy of the antenna spot beams, the spacecraft employs autotracking. The Ka-band command carrier uplinked from Cleveland is received by the spacecraft, any mispointing is determined, and the resultant azimth and elevation error signals, in digital form, are supplied to the atitude control subsystem. The autotracking function is redundant in active hardware areas.

During autotrack operation pointing of the Cleveland beam will be maintained within ±0.02° in both azimuth and elevation (pitch and roll, respectively) when all error sources are considered. This error is relative to a typical defined coverage region of a spot beam 0.24° in diameter. Coverage is specified with the pointing errors included. Further, spacecraft yaw errors yield a rotation of the beam pattern. Pointing errors due to yaw errors are less than 0.01°.

In order to meet these overall objectives, the autotrack function was designed to have a minimum operational range for azimuth and elevation error data output of 0.15° circular error (root-sum-square of azimuth and elevation errors) with respect to the autotrack null. Performance of this function is defined with respect to three annular subregions. These subregions, allowable errors in the subregions, and expected autotrack scale factors are given in table B-7.

TABLE B-7. - AUTOTRACK PARAMETERS

Operational subregion	Circular error (radii), deg	Autotrack scale factor, deg/count
Fine track	0-0.025	0.0019-0.0047
Intermediate track	0.025-0.165	0.0019-0.0047
Coarse track	0.165-0.25	0.0010-0.0043

For operational flexibility the attitude control subsystem can select either the spacecraft Earth sensor signal or the autotrack error signal for controlling the spacecraft attitude. The attitude control subsystem can add biases to the autotrack error signal for optimizing overall system pointing. The attitude control subsystem receives the autotrack update at a rate of four times per second.

Pointing errors for the transmitting beams are corrected by the receiving autotrack system, since the entire spacecraft attitude is corrected. Relative, static pointing errors between the receiving and transmitting beams are corrected by a bias pointing mechanism adjustment of the transmitting main reflector. The small corrections required of this reflector do not necessitate feed adjustments.

When the autotrack function is not operating, the spacecraft is controlled from an Earth sensor that maintains pitch (azimuth) and roll (elevation) within ±0.1° and yaw within ±0.13°. The autotrack acquisition range is ±0.2° minimum, which provides sufficient margin for autotrack acquisition upon return to the autotrack mode.

The Earth sensor assembly provides the pitch attitude reference for stationkeeping, and gyros are used for roll and yaw. However, as a result of the high disturbances produced by the thrusters, spacecraft pointing can degrade during stationkeeping periods to 0.13° in pitch and roll and 0.2° in yaw. In order to avoid impact on experiments, stationkeeping maneuvers will normally be conducted during periods when experiments are not at a critical point or are inactive. Experimenters will be notified when stationkeeping maneuvers are to be conducted. Planned periods are on weekends.

Onboard the spacecraft the autotracking function is accomplished by deriving azimuth and elevation signals from orthogonal TM_{01} and TE_{21} modes, which are excited in the tracking coupler. Azimuth and elevation error signals are biphase modulated and time multiplexed on the autotrack modulator. The error data modulate the TE_{11} sum (data) channel signal through a 10-dB coupler. The autotrack coupler output is routed to any of the four low-noise communications receivers via the WIRS assembly. The selected receiver downconverts the signal to intermediate frequency and then routes it to the redundant autotrack receivers. These receivers in turn demodulate and demultiplex the error signals and route them to an analog-to-digital converter. Digitized outputs are supplied to the attitude control subsystem.

Additionally, the autotrack receiver derives a measure of received signal strength from its automatic gain control voltage. This indication is inputted to the telemetry equipment for monitoring by the spacecraft control center.

ACTS GROUND SEGMENT

The ground segment shown in figure B-23 comprises the ACTS master ground station, the satellite operations center, and experimenter terminals. The ACTS master ground station is located at the NASA Lewis Research Center in Cleveland, Ohio. The satellite operations center, located at Martin Marietta Astro-Space in East Windsor, New Jersey, is linked to the master ground station by terrestrial voice and data circuits. The master ground station has only Ka-band communications, command, tracking, and telemetry capabilities. Transfer orbit support and operation backup to the satellite operations center will be provided by the C-band station Alpha located in Carpentersville, New Jersey. The Ka-band experimenter network will consist of the Earth terminals used by commercial, university, and government experimenters. These Earth terminals may have varying capabilities and throughputs ranging from full implementation of microwave-switch-matrix- or baseband-processor-mode communications to receiving only beacon signals for propagation modeling purposes.

Master Ground Station

The ACTS master ground station comprises the NASA ground station (NGS), the master control station (MCS), the microwave switch matrix-link evaluation terminal (MSM-LET), and the command, ranging, and telemetry (CR&T) ground equipment, which interfaces with the NGS at intermediate frequency. The Martin Marietta satellite operations center will monitor and control the ACTS housekeeping functions on a full-time basis.

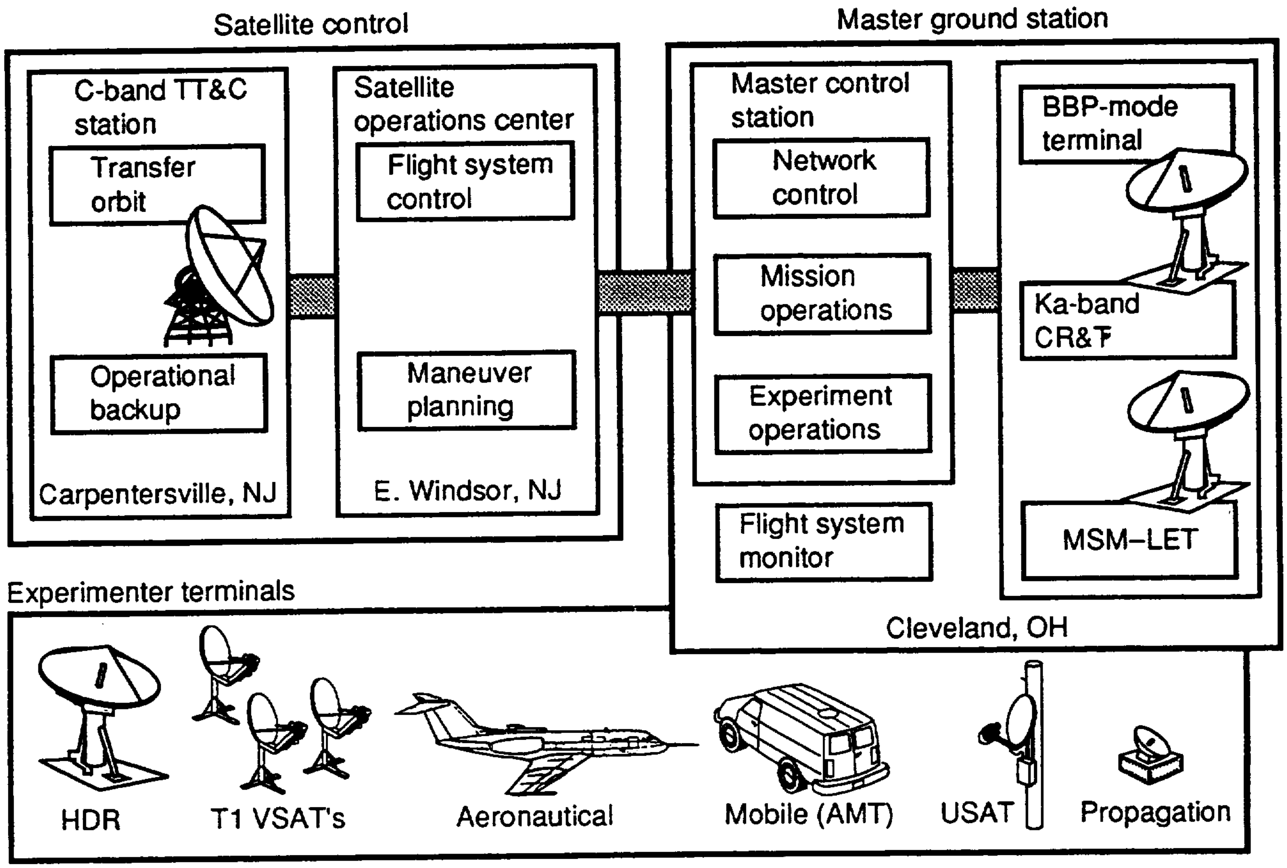


Figure B–23.—Functional overview of ACTS ground segment.

NASA ground station. - The NASA ground station functions as both a 27.5-Mbps-burst-rate and a 110-Mbps-burst-rate uplink traffic terminal as well as a command link to the spacecraft. It works in conjunction with the master control station to control the baseband processor network operation and may be configured to operate as one end of a point-to-point or point-to-multipoint user experimental network. The traffic terminals in the NGS have multiple T-1 and 6.312-Mbps serial data user interfaces to transfer communications data to and from the experimenter.

The NASA ground station provides all signal processing needed to communicate with ACTS. It contains the radiofrequency and signal-processing equipment that supports the baseband processor mode of operation as well as the Ka-band CR&T signals. The terminal utilizes a nominal 5.5-m-diameter Cassegrain antenna to provide reception at 20 GHz and transmission at 30 GHz.

The radiofrequency terminal antenna is designed to operate in the 20- and 30-GHz bands with nominal gains of 56.7 dB at 20 GHz and 60.2 dB at 30 GHz. The antenna can transmit and receive on both linear polarizations simultaneously. The antenna has a limited-motion mount that enables it to illuminate the geostationary arc between 80° and 110° W longitude. The antenna can be pointed 2° north or south of the arc as well. The nominal pointing to the ACTS satellite is an elevation of 39° and an azimuth of 206°. The transmitters are located inside the building underneath the antenna. The transmitters connect with a rigid waveguide directly to the feed horn. The feed horn, which is also within the building, radiates vertically upward into the beam waveguide. The beam waveguide transmits the radiated power, by means of the reflecting mirror on the antenna motion axes, to the subreflectors and the main reflectors.

Antenna pointing is controlled by a tracking loop. The tracking loop is implemented as a step tracker that seeks to maximize the amplitude of one of the two 20-GHz telemetry beacons transmitted by the satellite. The nominal pointing accuracy is within ±0.02° of the peak of the beam being tracked.

The transmitting side of the baseband-processor-mode terminal accepts digital inputs from the TDMA equipment at data rates of 27.5 or 110 Mbps and modulates the information onto an intermediate-frequency carrier at about 3 GHz. The three intermediate frequencies in the 3-GHz band correspond to three uplink channels at 29.263, 29.242, and 29.298 GHz. There are two operational baseband processor modulators, one for each data rate. Each modulator can be operated at one-half the nominal symbol rate when it is required to transmit coded signals. The output ports of the two modulators are combined into a signal upconverter and transmitter chain. Because system operation is such that the 27.5- and 110-Mbps signals are transmitted only one at a time, no interaction occurs between the two channels. The 110-Mbps modulator operates in a fixed frequency channel at 29.263 GHz. The 27.5-Mbps modulator can operate in either of two channels, where the channel can be selected by a front panel control. The 27.5-Mbps uplink channel frequencies are 29.242 and 29.298 GHz.

The baseband-processor-mode upconverter chain uses double conversion from 3 to 15 GHz and then to 30 GHz. The 30-GHz signal is amplified by a two-for-one redundant TWTA to a power level of 60 W before being routed to the antenna, from where it is radiated by vertical polarization. The transmitted effective isotropic radiated powers (EIRP's) are 74 and 68 dBW for the 110- and 27.5-Mbps channels, respectively. Filter elements in the intermediate-frequency part of the baseband processor channel (at 3 GHz) are used as equalizers to minimize the intersymbol interference.

The power amplifier is followed by a high-power filter that is used to control harmonic and spurious outputs. This filter also attenuates energy at the uplink beacon frequency of 27.505 GHz. The uplink beacon is received at the Earth terminal on the same vertical polarization as the baseband-processor-mode transmission; therefore, the beacon receiving channel is very susceptible to baseband processor transmitter leakage. (See fig. B-24.)

The receiving side of the baseband-processor-mode terminal receives a single horizontally polarized downlink carrier at 19.49 GHz, which under clear-sky conditions is modulated with 110-Mbps information. Using the same antenna as the transmitted signals, the received carrier is routed to a GaAs field-effect-transistor, low-noise amplifier. The receiving channel operates with a nominal gain-to-noise-temperature ratio of 27 dB/K. Appropriate reliability is ensured by providing three-for-two redundancy for this amplifier. After amplification the 20-GHz signal is downconverted, by using double conversion, to 12 and then 3 GHz. The baseband-processor-mode receiver is also used to receive the horizontally polarized telemetry beacon from the spacecraft at 20.195 GHz. Couplers and filters separate these two signals in the 20-GHz band. Figure B-25 shows the receiver's capability to receive the baseband processor signal and the 20.185-GHz beacon on the vertical polarization.

The downconverted baseband-processor-mode signal is demodulated, and the 110-Mbps data (received under clear-sky conditions) are transmitted to the TDMA equipment. Under rain fade conditions the received symbol rate is reduced to 55 Mbps and the demodulator operating mode is selected to process coded traffic.

Master control station. - The master control station (MCS) provides baseband processor (BBP) network operation and BBP experimenter operation and coordination.

Baseband processor network operations consist of controlling the BBP onboard the ACTS and the BBP network of Earth terminals. For hopping beam BBP-mode operations, demand-assignment multiple access is provided by the MCS. Initial setup of beam dwell times and hopping sequences is completed off-line. For a particular beam dwell time and hopping schedule, access is provided on a real-time basis.

The master control station contains the computer hardware and software to coordinate TDMA traffic flow. It uses the VAX 8600 computer to direct the real-time network activities, to develop TDMA burst time plans, and to respond to demand-assignment requests. The off-line functions of archiving and retrieving experiment data are the responsibility of the MCS. It also serves as a backup for configuring the MCP, a function that is normally performed by the spacecraft operations center.

Experiment operations consist of coordinating the conduct of the BBP-mode experiments and recording experiment data for transfer to the BBP-mode experimenters. In the microwave switch matrix mode of operation the MCS performs an initialization function for all high-burst-rate experiments.

Spacecraft command, ranging, and telemetry. - The radiofrequency terminal transmits the Ka-band command signals to the spacecraft at a frequency of 29.975 GHz with an EIRP of 77.5 dBW. The command carrier is transmitted at all times, even when there are no commands to be sent to the spacecraft, because the command carrier is used by the spacecraft as its tracking beacon. The command modulation is derived from Martin Marietta-supplied CR&T equipment located in Building 55 at Lewis.

The three downlink beacons at 20.185, 20.195, and 27.505 GHz have three purposes:

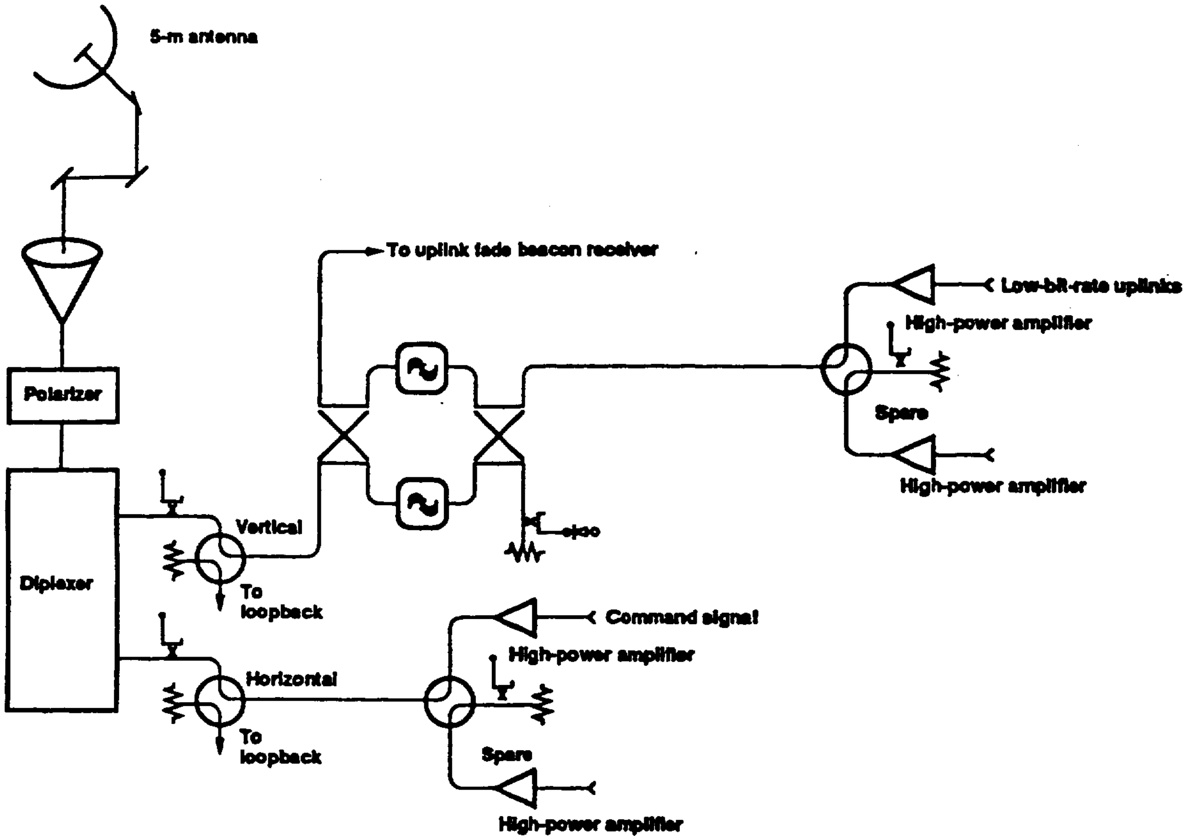


Figure B-24. — Radiofrequency terminal transmitting paths.

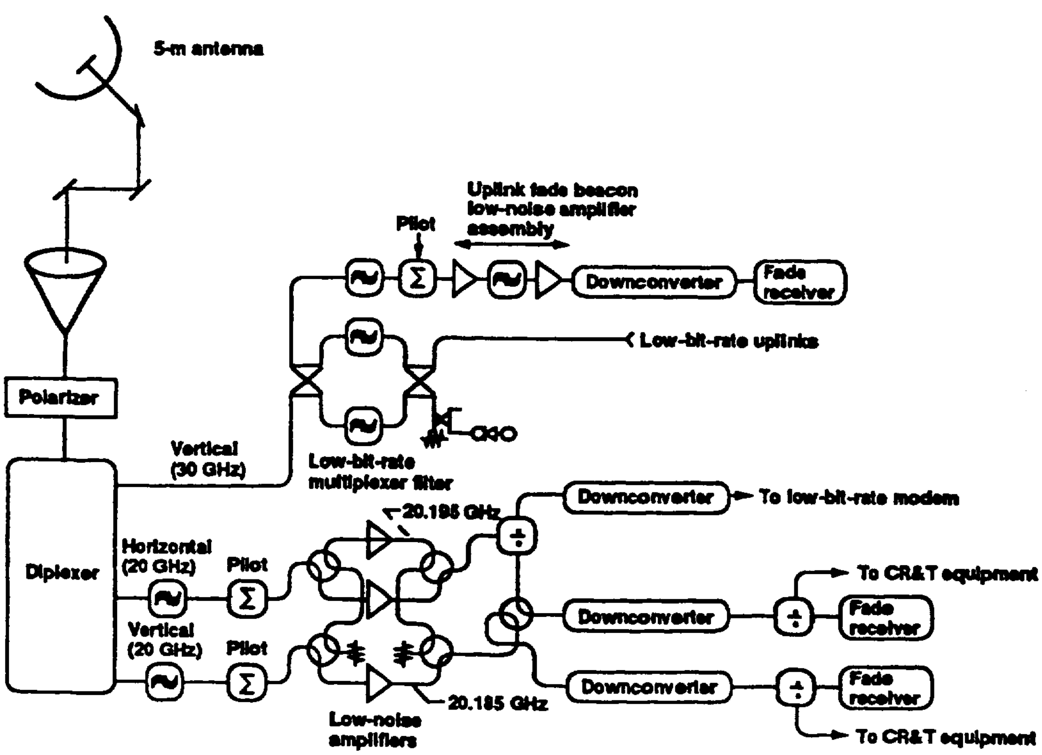


Figure B-25. — Radiofrequency terminal receiving paths.

(1) To carry spacecraft telemetry
(2) To point the Earth terminal antenna
(3) To measure rain fades

The horizontally and vertically polarized 20-GHz beacons can be used for all three purposes. The 27.5-GHz beacon will be used only for measuring rain fade.

The radiofrequency terminal receives the two spacecraft telemetry beacons at 20.185 GHz (vertical) and 20.195 GHz (horizontal). The telemetry receiving channel operates with a nominal gain-to-noise-temperature ratio of 27 dB/K. These signals are amplified and downconverted as described in the previous section on rain fade processing. The two 70-MHz downconverted signals are power divided and directed to the telemetry demodulators and the rain-fade-measuring equipment.

For satisfactory operation of the rain-fade-measuring equipment (which measures only the strength of the telemetry carriers), the frequency modulation (telemetry and ranging) put onto the carriers must have a constant modulation index so as to preserve a constant transmitted carrier amplitude.

Rain fade measurements. - A major operational feature of the ACTS system is the use of rain fade compensation. The rain fade compensation schemes require real-time information on the attenuations occurring on the uplink and downlink between the spacecraft and each Earth terminal. This attenuation is determined by measuring the received signal strength of three beacons transmitted by the spacecraft. These three beacons are the two 20-GHz telemetry beacons and a 27.505-GHz beacon provided specifically for rain fade measurements in the uplink frequency band. This section describes the processing of the beacon signals from 20 and 30 GHz to a 70-MHz interface.

Downlink beacons: The two telemetry beacons have separate linear polarizations. The horizontal beacon at 20.195 GHz is received in the same low-noise amplifier as the baseband processor signal and is coupled off and bandpass filtered before double-frequency downconversion to a 70-MHz interface. The vertical beacon at 20.185 GHz is received by a separate low-noise amplifier before similar downconversion. Both beacons are power divided at the 70-MHz interface and routed on two paths: one to the telemetry demodulators, and the other to the beacon processors.

Uplink fade beacon: This beacon at 27.505 GHz is actually downlinked from the spacecraft. The designation "uplink" in the title refers to the frequency band of the beacon, not its direction of propagation. When this vertically polarized beacon is received, it is amplified by a dedicated low-noise receiver that downconverts it to a 70-MHz interface and then transmitted to the beacon processor.

Experimenter Support

The master control station provides several features for supporting experimenters in setting up experiments and for managing data generated during experiments.

The experiment configuration subsystem provides the user with the ability to use the telemetry data that are generated during real-time operation of the satellite. For example, the experimenter will be able to define certain parameters that affect the performance of the demand-assigned multiple access (DAMA) algorithm in order to optimize blocking rate and response time tradeoffs for different traffic mixes.

The experiment data-processing subsystem provides various data base commands and tools to aid the experimenter in managing data recorded during an experiment. These data will include performance data generated by the baseband-processor- and microwave-switch-matrix-mode network control subsystems, telemetry data recorded by the multibeam communications package telemetry and control subsystem, and measurements such as beacon power levels and bit error rate made at the NASA ground station.

Baseband processor TDMA Earth terminal equipment. - The TDMA equipment indicated in figure B-26 is housed in experimenter Earth terminals and operates under direction of the master control station. It interfaces with the user through the input/output interface to the radiofrequency subsystem via the modulation/demodulation equipment and to the master control station to exchange orderwire and status information. Specifically, the experimenter's Earth terminal TDMA equipment must perform the following functions:

(1) Acquire and synchronize to the flight system's baseband processor.

(2) Multiplex input/output interface channels into flight system channels, in increments of 64 kbps, according to the burst time plan that is received from the master control station via the outboard orderwire (OBOW) channel.

(3) Receive the baseband processor burst, remove designated channels, and route these channels to the assigned input/output interface.

(4) Receive orderwires from the master control station containing information for new burst time plans based on demand-assignment processing and used for coding and data rate changes based on link attenuation measurements. Transmit a burst whose length, duration, and frame position are defined by the burst time plan received from the MCS.

(5) Maintain synchronization of transmitting burst frame positions by using the tracking error word received from the flight system in the downlink burst.

(6) Maintain synchronization of receiving burst frame positions by uncoded word detection of the downlink burst.

(7) Control routing to and from the input/output interface.

(8) Selectively apply forward-error-correction coding and decoding.

The baseband processor system is required to transmit to the flight system on either a 27.5-Msps TDMA carrier or a 110-Msps TDMA carrier; it receives a single 110-Msps downlink burst from the flight system.

Baseband-processor-mode modulation subsystem. - The modulation subsystem's basic elements are shown in figure B-27, a simplified block diagram of the baseband-processor-mode communications system. The uplinks are supported by two types of dual-rate modulators. One type is capable of transmitting at nominally 27.5 Msps in the clear-sky mode and at 13.75 Msps in the rain fade mode. The other type is capable of transmitting at nominally 110 Msps in the clear-sky mode and at 55 Msps in the rain fade mode. Time- and frequency-division multiple access operation with one 27.5/13.75-Msps modulator and one 110/55-Msps modulator is employed in the NASA ground station. In any given experimenter Earth terminal, one modulator of either type would be normally

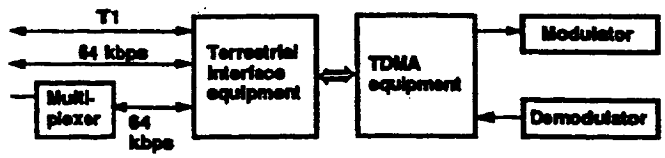


Figure B-26. — User's terrestrial interface to TDMA equipment.

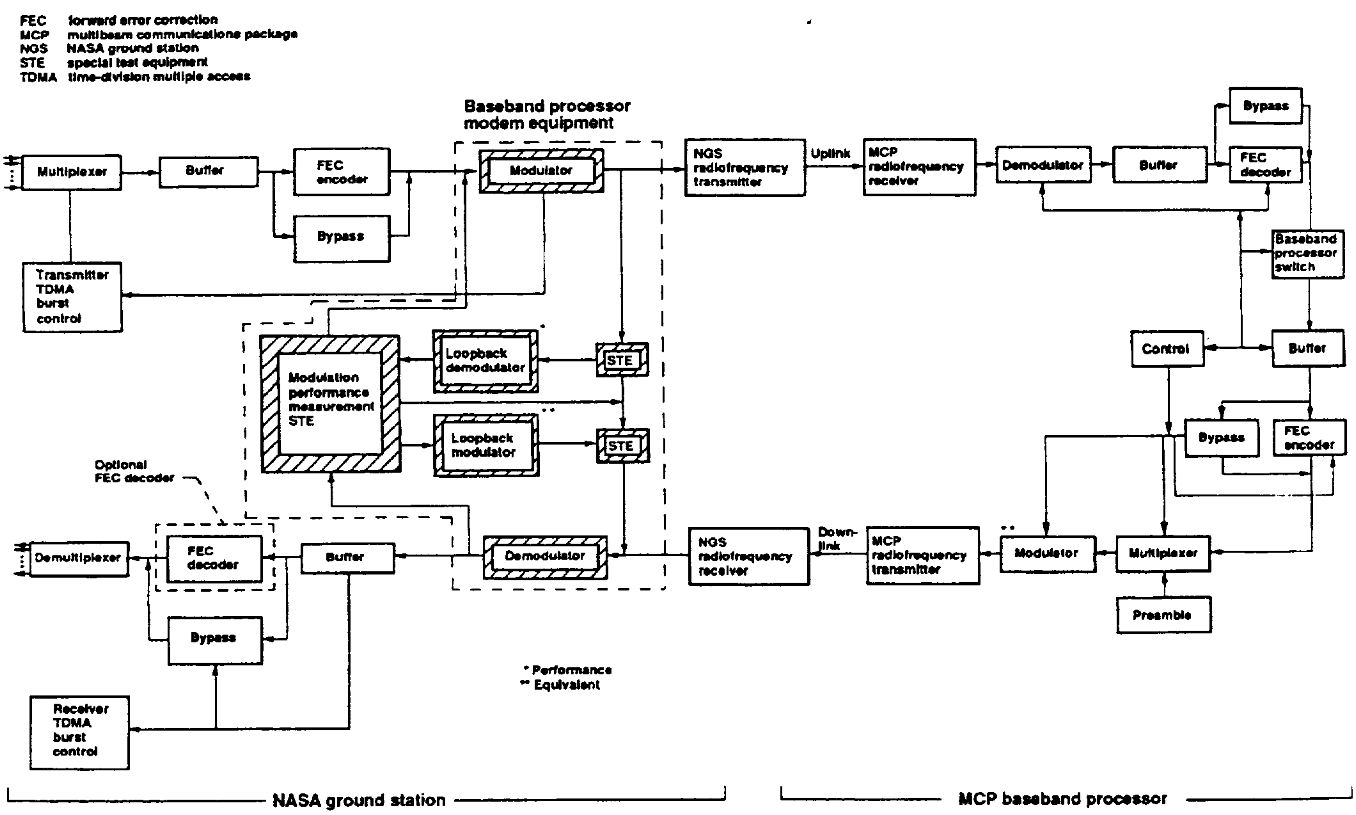


Figure B-27. - Simplified block diagram of baseband-processor-mode communications system.

used. (In the clear-sky, or uncoded, mode one symbol per second equals one bit per second of traffic.)

The baseband-processor-mode downlink is supported by another type of dual-rate demodulator at the NASA ground station and experimenter Earth terminals. The clear-sky modulation rate is nominally 110 Msps, and the rain fade rate is 55 Msps. This demodulator is very similar to the 110/55-Msps uplink baseband processor demodulator.

The NASA ground station and experimenter Earth terminals will contain modulation and demodulation equipment that does not form a compatible modem pair capable of simple traditional loopback modem performance checks. The NASA ground station modulators have been specified to ensure that certain performance results are achieved when transmitting to the corresponding spacecraft baseband processor dual-rate uplink demodulators. The NASA ground station's downlink demodulator has been specified in such a way as to ensure that certain performance results are achieved when receiving from the spacecraft's baseband processor downlink modulator.

In order to guarantee that the required performance specifications of baseband-processor-mode uplinks and downlinks are met, uplink demodulator and downlink modulator emulation equipment is being provided to test the corresponding operational NASA ground station modulator and demodulator equipment in a loopback mode. The appropriate hardware that will have performance equivalent to the baseband processor hardware but will be packaged for the NASA ground station application is being procured.

Figure B-28 shows the loopback emulator equipment as part of the NASA ground station. For the uplink two dual-rate demodulators are necessary, one compatible with each of the 110/55-Msps and 27.5/13.75-Msps uplink modulators. For the downlink one dual-rate modulator compatible with the NASA ground station's demodulator is required.

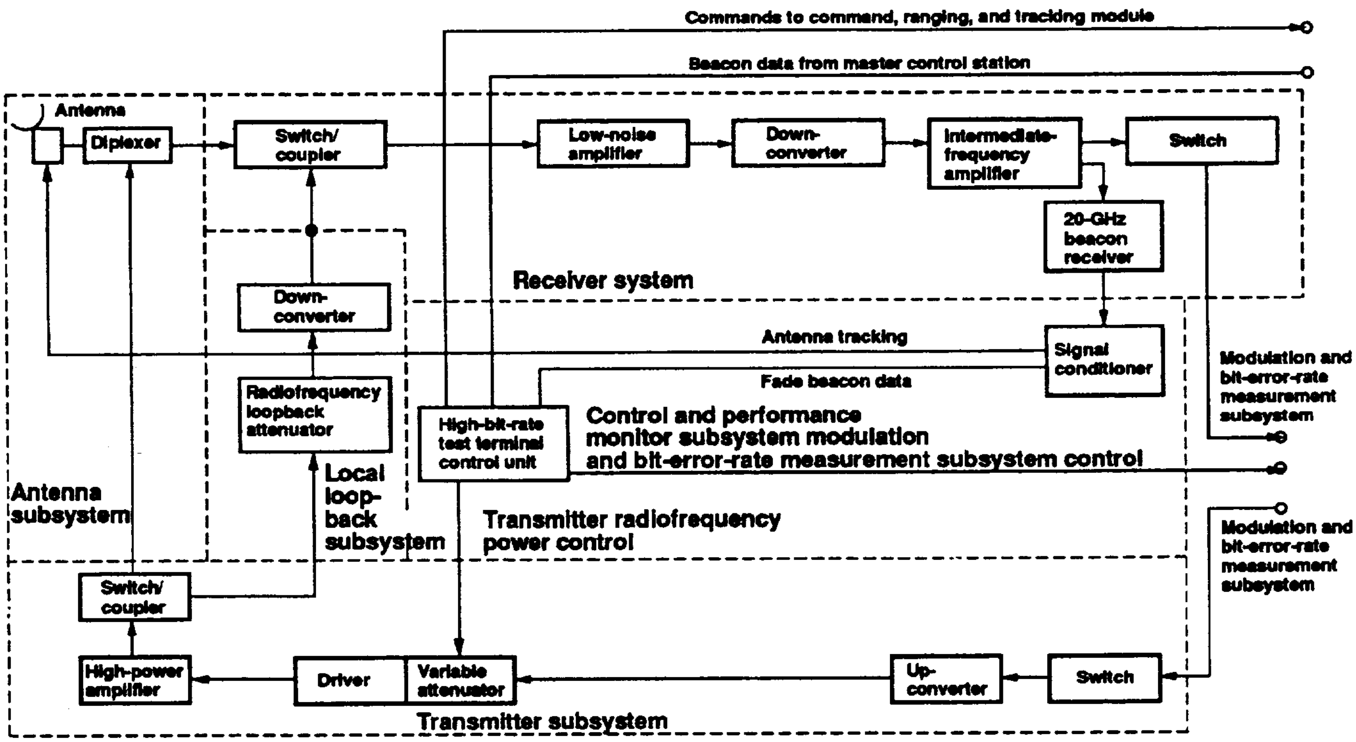
The implementation of an experimenter Earth terminal will also require up- and downlink emulator equipment for modem loopback testing.

In addition to the modulation equipment special test equipment is necessary (fig. B-28) for appropriate performance testing of uplink and downlink modem equipment at all uncoded and coded rates over the ranges of expected ratio of energy per symbol to noise density and bit error rate.

The modulation subsystem's elements function with forward-error-correction decoding. On the uplink the decoder is part of the spacecraft's baseband processor equipment. On the downlink the decoder is separately packaged with appropriate provision for interfacing from and to the TDMA receiving burst controller.

Microwave-switch-matrix-mode equipment. - The link evaluation terminal includes all equipment required to provide the 30-GHz transmitting and 20-GHz receiving capability for ACTS communications experiments that use the microwave switch matrix. A block diagram of this terminal is shown in figure B-28. It consists of the following six major subsystems:

(1) Antenna
(2) Radiofrequency transmitter



O known interface port
SMSK serial minimum-shift keyed

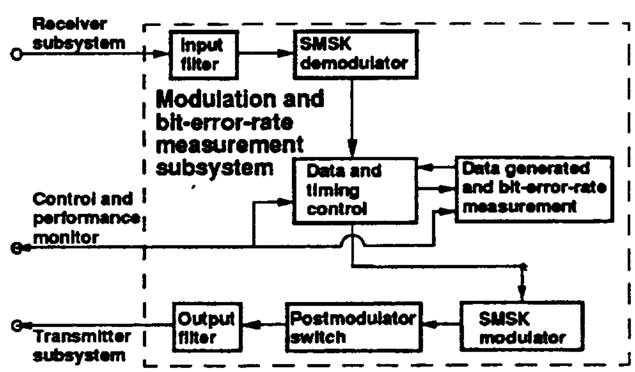


Figure B-28. — Block diagram of high-bit-rate link evaluation terminal.

(3) Radiofrequency receiver
(4) Control and performance monitor subsystem
(5) Local loopback at radiofrequency
(6) Modulation and bit-error-rate measurement

The link evaluation terminal transmits a modulated signal at a frequency between 29.1 and 30.0 GHz and receives a modulated signal at a frequency between 19.2 and 20.2 GHz for ACTS communications experiments. The uplink EIRP can be varied in a controlled manner over a 10-dB range from 69 to 79 dBW by varying the radiofrequency output power as required by local climatic conditions and as indicated by downlink beacon measurements at 20 and 30 GHz made by the NASA ground station. The radiofrequency power is controlled by varying the drive level to the high-power amplifiers. The controlled radiofrequency power can follow increasing or decreasing rain fade conditions. The communications link is maintained during power transition.

The transmitting and receiving polarizations are orthogonal (horizontal or vertical) and linear (horizontal or vertical). The primary mode of operation shall be the horizontal transmitting, vertical receiving mode, which corresponds to the ACTS fixed-beam antenna pointed at the NASA ground station.

The receiver portion of the link evaluation terminal can receive and demodulate SMSK 220-Mbps modulated signals from the spacecraft. The effective antenna gain-to-noise-temperature ratio is 27 dB/K. The total bit error rate will not exceed 10^{-6} during clear-sky conditions or during rain fades of up to 10 dB.

The control station of the link evaluation terminal is located with the master control station and the NASA ground station in Building 55 at Lewis. The link control station will interface with the master control station's CR&T section to send

(1) Multibeam communications package commands in the form of configuration requests
(2) Microwave switch matrix on/off commands
(3) Downlink TWTA high or low power settings

and to receive

(1) Beacon measurements at 20.185, 20.195, and 27.505 GHz in a yet-to-be-determined format
(2) Ephemeris and range data
(3) Telemetry data displays via video display terminal
(4) Timing reference signals
(5) Alarm and monitor data

Modulation format choice. - The link evaluation terminal can adequately support the 220-Mbps SMSK burst modem without any forward error correction. The serial minimum-shift keying requires a null-to-null spectrum occupancy of 1.5 X 220 = 330 MHz. The transponder's 1-dB bandwidth is actually 900 MHz and could support two 220-Mbps or one 600-Mbps minimum-shift keying transmission experiment. By connecting to the intermediate-frequency input and output ports of the link evaluation terminal, other forms of modulation such as quaternary phase-shift keying (QPSK), offset QPSK, binary phase-shift keying (BPSK), and frequency modulation could be used if the user supplied the appropriate equipment. The use of forward error correction would be an option the user could supply in his or her equipment as long as the required bandwidth remained within the transponder bandwidth.

NETWORK CONTROL

General Role of Master Control Station

The master control station controls and monitors the baseband processor's TDMA mode and the rest of the multibeam communications package. It also supports ACTS experimenters with experiment configuration control and experiment data management. The master control station's functions are implemented in software run on several general-purpose minicomputers located at Lewis.

The TDMA network control function of the master control station initializes and acquires the BBP-mode terminals, allocates space segment capacity on a DAMA basis, provides rain fade compensation for all TDMA Earth terminals, and continuously monitors the status of each terminal in the network. It also provides command and display functions for the operators at the NASA ground station and records data on the performance of the network control system.

In conjunction with its network control functions the master control station provides real-time control of the baseband processor and the associated hopping-beam antenna onboard the spacecraft. The baseband processor and antenna are programmed to provide communications capacity in response to dynamically varying traffic conditions. Baseband processor control is normally provided by command and status channels in the TDMA uplink and downlink. Backup control of the baseband processor and other multibeam communications package components is provided via the housekeeping telemetry and command channels.

The master control station also records measurements made by the NASA ground station's baseband processor and TDMA radiofrequency equipment. These include frequency, power, and bit-error-rate measurements made on the ACTS communications signals and the beacon signals.

Experimenter-selectable parameters and options are provided that afford the experimenter flexibility in configuring the master control station's software functions to his or her particular experimental requirements.

The master control station serves as a central repository for experiment data generated at the NASA ground station. A data base management facility is provided so that desired portions of the experiment data base can be extracted and made available to individual researchers for detailed data analysis.

The following sections describe in more detail the major subsystems of the master control station.

Baseband Processor Network Control Subsystem

The baseband processor communications networks are controlled in the master control station by the baseband processor network control subsystem. The primary functions of this subsystem include real-time allocation of space segment capacity for single-channel (64 kbps) and multiple-channel (n X 64 kbps) circuits by using a DAMA algorithm, control of forward-error-correction data encoding at the traffic terminals and at the baseband processor during rain fade situations, monitoring of the active TDMA traffic terminals, and operator control and monitoring of the performance of the baseband processor TDMA network. Specifically, this subsystem performs the following functions:

(1) Process capacity requests received from the traffic terminals via the inbound orderwire (IBOW) for single- and multiple-channel (64 kbps/channel) point-to-point circuits (simplex or duplex) and point-to-multipoint circuits (simplex only) by using a real-time DAMA algorithm.

(2) Provide compensation for rain fade by using adaptive forward error correction, both uplink and downlink.

(3) Transmit the necessary burst time plan information to each baseband processor traffic terminal via the outbound orderwire (OBOW) to affect required changes in capacity allocation for DAMA and rain fade compensation.

(4) Generate commands to the multibeam communications package's telemetry and control subsystem (part of the master control system) for control of the baseband processor and hopping-beam antennas onboard the spacecraft.

(5) Control acquisition into the network of all traffic terminals.

(6) Provide the baseband processor network operator with control of network startup and shutdown, displays of network status and performance measurements, and notification of any alarm conditions indicating network malfunctions.

(7) Archive data pertinent to off-line analysis of network performance.

Microwave Switch Matrix Network Control and Performance Subsystem

The link evaluation terminal contains the network control and performance monitoring subsystem, which controls the microwave switch matrix communications network. It interfaces with the NASA ground station as shown in figure B-29. It can generate commands to the multibeam communications package onboard the spacecraft via the command link. These commands adjust the traveling-wave tube power levels in order to compensate for signal fading. Telemetry data from the spacecraft are monitored and used to generate both a video terminal display and a hard-copy printout of the status of the link evaluation terminal. A bit-error-rate measurement subsystem is also included to determine the performance of the 220-Mbps modems.

Multibeam Communications Package Telemetry and Control Subsystem

This subsystem provides the interface between the other master control station subsystems and the multibeam communications package on the spacecraft. Commands to the multibeam communications package are routed to the appropriate NASA ground station equipment for transmission to the spacecraft. Telemetry and status data from the multibeam communications package are received from the NASA ground station and stored or routed as required to the other master control station subsystems. Specifically, the telemetry and control subsystem performs the following major functions:

(1) Receive, time stamp, and archive all spacecraft telemetry data.

(2) Process the multibeam-communications-package-related telemetry to monitor the status of its components.

(3) Provide real-time control of the baseband processor by using commands from the BBP-mode network control subsystem, and provide backup manual

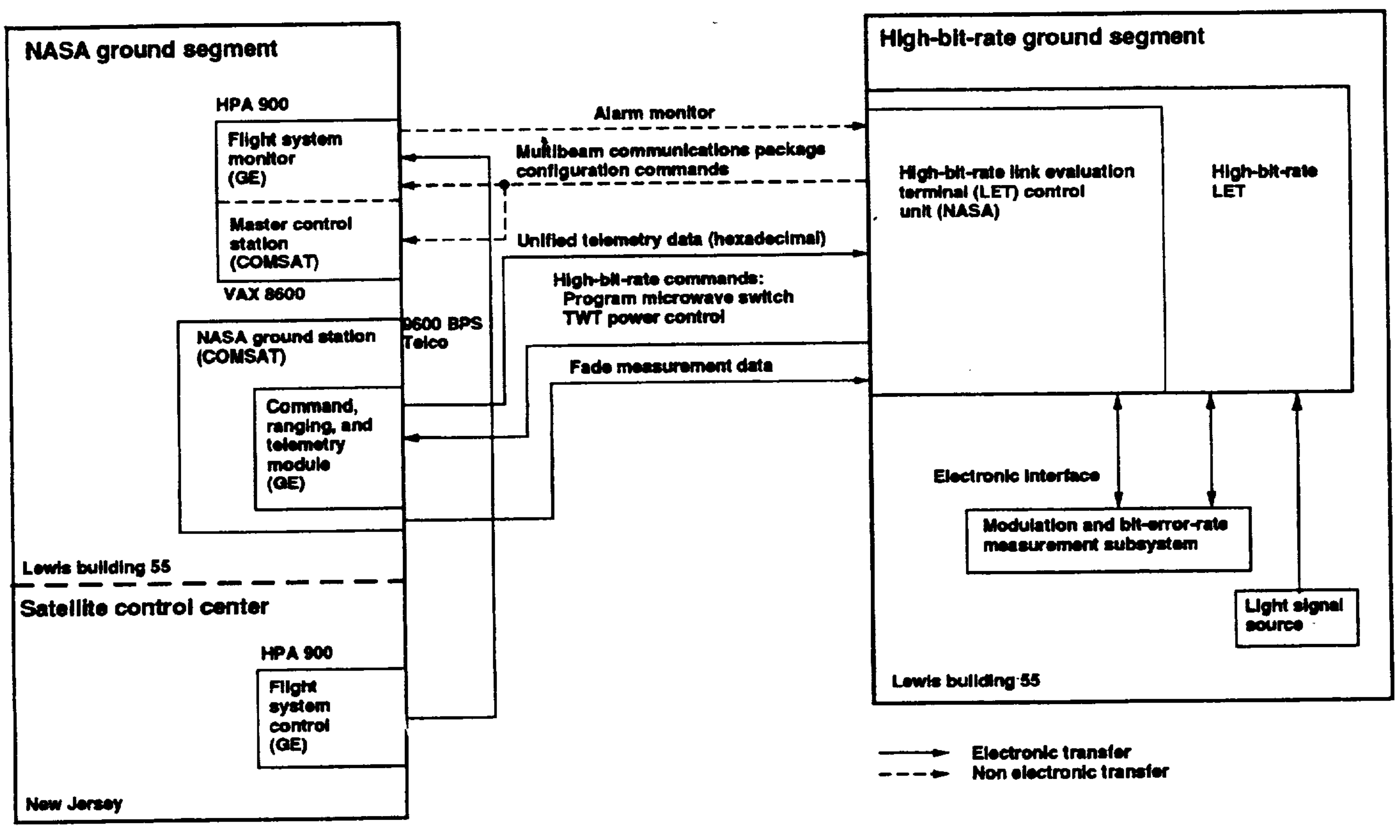


Figure B-29. — Interface between NASA ground station and high-bit-rate link evaluation terminal.

control of the baseband processor for diagnostics or nonnetworking experiments.

(4) Provide real-time control of the microwave switch and downlink power by using commands from that subsystem, and provide manual control of the microwave switch and downlink power for diagnostics or nonnetworking experiments.

(5) Control the initialization and shutdown sequences for the multibeam communications package.

(6) Control the hopping-beam antennas, in conjunction with either the baseband processor or the microwave switch.

(7) Provide the multibeam communications system operator with control and monitoring functions associated with each of the preceding functions.

Orderwire Services

The ACTS baseband processor and microwave switch matrix TDMA communications networks are centrally controlled by their own control stations. The baseband processor is controlled by an orderwire circuit between each experimenter Earth terminal and the control station. Capability to control the microwave switch matrix network by using TDMA can be added. These orderwires are provided as dedicated circuits within the TDMA networks.

The IBOW carries request and status information from the Earth terminals to the control station. The OBOW carries network control information, such as burst time plan data, from the control station to the Earth terminals. Each Earth terminal can send one IBOW message to the control station during every superframe (i.e., every 75 msec), yielding an IBOW capacity of approximately 13 messages per second for each terminal. The effective OBOW capacity is 333 messages per second (one message per millisecond, repeated three times), with each message broadcast to every Earth terminal.

The available inbound baseband-processor-mode orderwire messages include

(1) No operation
(2) Capacity request
(3) Circuit disconnect
(4) Forward-error-correction request
(5) Station status
(6) N-channel capacity request
(7) N-channel disconnect
(8) N-channel accept

and the outbound messages include

(1) No operation
(2) Circuit assignment
(3) Disconnect acknowledgment
(4) Disconnect confirmation
(5) N-channel disconnect acknowledgment
(6) N-channel status
(7) N-channel port request
(8) Uplink burst assignment

(9) Downlink burst assignment
(10) Burst slot movement
(11) Acquisition parameters
(12) Supervisory command

These terms are defined in table B-8.

TABLE B-8. - ORDERWIRE DEFINITIONS

Term	Definition
No operation	Used when no other message is pending
Capacity request	Requests master control station to establish new 64-kbps circuit
Circuit disconnect	Notifies master control station that an existing circuit is no longer needed
Forward-error-correction request	Requests master control station to enable or disable forward error correction on uplink or downlink at Earth terminal
Station status	Indicates status of Earth terminal and also contains transmitting/receiving frame offset used to compute range to spacecraft
N-channel capacity request	Requests master control station to establish a new multichannel (N x 64 kbps) circuit
N-channel disconnect	Notifies master control station that an existing N-channel circuit is no longer needed
N-channel accept	Is sent by destination terminal to acknowledge to master control station that capacity to service an N-channel circuit is available
Circuit assignment	Instructs Earth terminal where to locate particular single-channel circuit in TDMA frame
Disconnect acknowledgment	Instructs Earth terminal to disconnect a 64-kbps satellite channel from a particular terrestrial circuit
Disconnect confirmation	Informs Earth terminal requesting a disconnect that master control station no longer maintains circuit active
N-channel disconnect acknowledgment	Instructs Earth terminal to disconnect N-channel circuit
N-channel disconnect confirmation	Informs Earth terminal that N-channel disconnect is complete
N-channel status	Informs terminal originating an N-channel request of acceptance or denial
N-channel port request	Used by master control station to ask destination terminal referenced in an N-channel request if it has port available with sufficient capacity
Uplink burst assignment	Defines position and length of transmitting burst for Earth terminal
Downlink burst assignment	Informs Earth terminal where to locate downlink burst in TDMA frame
Burst slot movement	Instructs Earth terminal to move an existing circuit from one TDMA slot to another
Acquisition parameters	Provides Earth terminal with position and length of acquisition window in TDMA frame
Supervisory command	Used by master control station to enable or disable requests from any Earth terminal

SECTION C

BASEBAND PROCESSOR MODE OF OPERATION

DETAILED DESCRIPTION OF SATELLITE HARDWARE

Radiofrequency Hardware

The multibeam communications package provides uplink and downlink scanning beams, redundant receivers and transmitters, redundancy switching, data demodulation and modulation, and baseband processing. A detailed switching diagram of the baseband processor portion of the package is shown in figure C-1. Included is the capability to do forward error correction.

The multibeam communications package receives the baseband-processor-mode signal through the hopping-beam antenna. The scan location is controlled by the beam-forming network under program control stored in the baseband processor. The signal then shares a common path with the microwave-switch-matrix mode signal through the WIRS and the downconverter. The receiver does not hard limit the signal, since each beam can contain two frequency-division-multiplexed channels. The signal path is linear with a 1-GHz bandwidth. The signal from the receiver then passes through a receiver coaxial switch assembly (RCSA). The switches in the RCSA are used to select two of four possible receivers for controlling the routing of the frequency-division-multiplexed channels in the two uplink beams to the correct baseband processor input port. The baseband processor provides demodulation, input buffering, decoding for faded channels, data routing, output buffering, encoding, and modulation for downlink transmission. The baseband processor's output is routed by the transmitter coaxial switch assembly (TCSA). One set of switches is used to route undesired output channels to resistive loads. A second set of switches in the TCSA allows each output beam to be routed to one of four possible transmitters. The signal is amplified to saturation by a solid-state amplifier and then injected into the TWTA. The output is routed by the WORS to the downlink hopping-beam antenna.

For a detailed description of the operation and interconnection of the waveguide redundancy switches and the interconnection with the multibeam antenna, refer to the "Multibeam Communications package" subsection of section B.

Baseband Processor

In the baseband processor mode of operation all dynamic control of the multibeam communications package is through the baseband processor. A block diagram of the baseband processor is shown in figure C-2. The baseband processor operates as a pipeline processor with three stages of message processing:

(1) Message input - The baseband processor receives TDMA data through the SMSK-modulated uplink and acquires carrier and bit synchronization. The messages are demodulated by a set of parallel demodulators. One or two 110.592/55.296-Msps demodulators may be active at one time, allowing a maximum throughput of 221.184 Mbps. A pair of narrowband demodulators operating at 27.648/13.824 Msps may be activated in place of a wideband demodulator in either of the channels. The messages are stored sequentially in input memories. Coded messages are decoded after they are stored in the input memories if directed by program control.

(2) Message routing - The baseband processor reads individual messages from

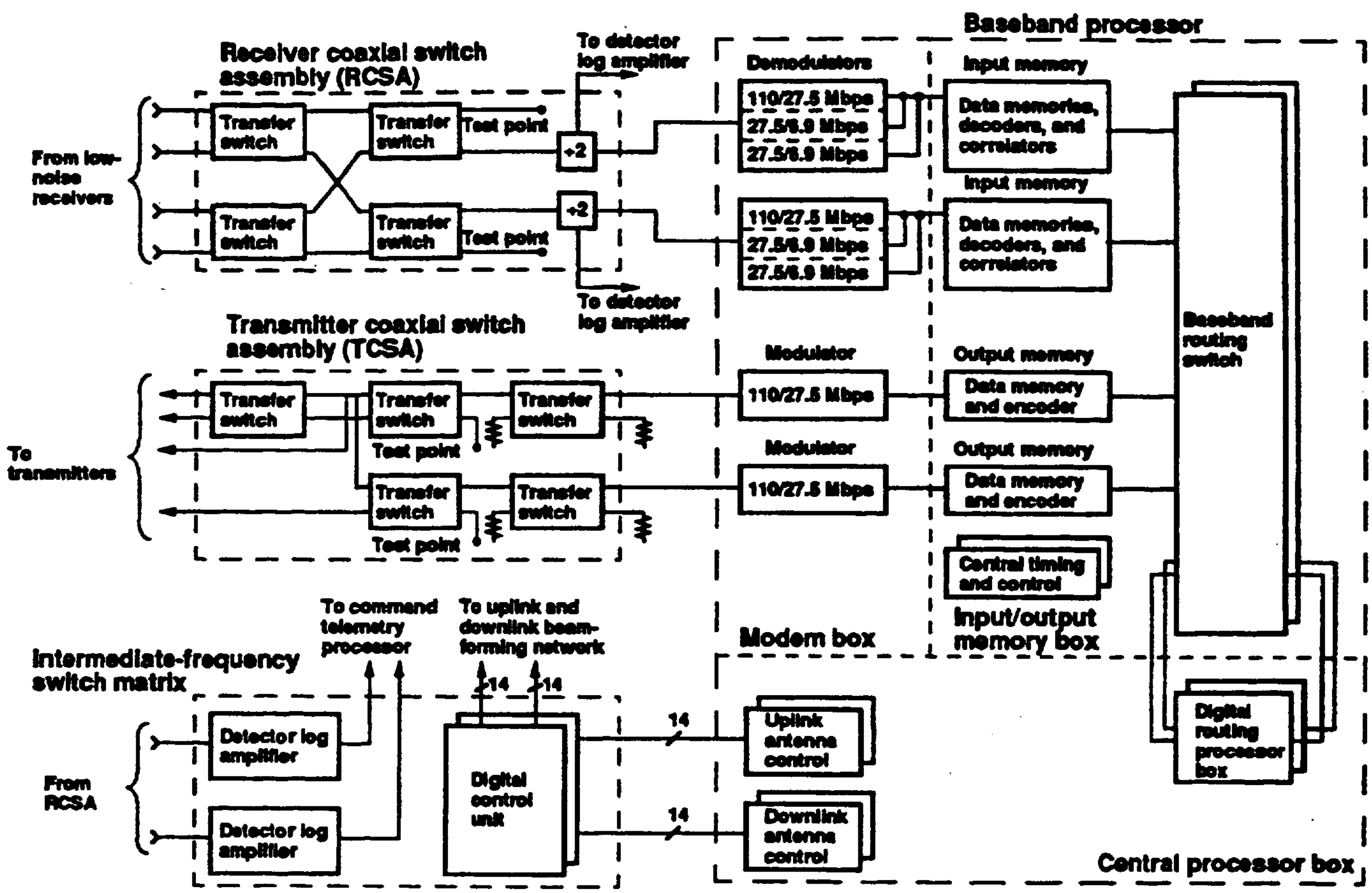


Figure C-1. – Detailed switching diagram for baseband processor.

the input memories in a random-access fashion and routes each message through a three-by-three baseband routing switch. The routing switch allows the baseband processor to direct messages transmitted on any frequency-division-multiplexed channel on either of the uplink hopping beams to one of the output memories. The output memory services one of the two downlink hopping beams. The third set of input and output ports in the baseband routing switch directs uplink control directives to the digital routing processor and provides a path for it to insert status messages and preamble data into the downlink data path.

(3) Message output - The baseband processor reads messages from the output memories in a random-access manner and feeds these data to the forward-error-correcting convolutional encoder (if directed by program control). The messages are then routed to the downlink SMSK modulators. The message flow is shown in figure C-3.

Both the central processor box, which includes the digital routing processor and uplink and downlink hopping-beam antenna memory maps, and the baseband routing switch in the input/output memory box are redundant. Switching from the primary to the redundant side for any single redundant function requires that all redundant functions be switched also.

All throughput data-processing functions that have been described are controlled by memory map programming. Nine memory map functions provide separate control for the input demodulators (two), the input memories (two), and the uplink and downlink antenna scan controls (two), the routing switch (one), and the output memories (two). Each map contains 1728 active locations (one for each slot). Memory map commands are always executed in a sequential fashion.

Each memory map location contains up to 24 bits (including one parity bit) that define the state of the corresponding active function. Memory map functions are described later in the subsection "Definition of Memory Map."

Each memory map function includes two sets of memory maps: one denoted foreground, and one background. The foreground map is defined to be the one currently active. The multibeam communications package can update the frame configuration by updating the contents of the background memory map only. Control directives to update memory are normally transmitted via the baseband-processor-mode uplink, although the CR&T link can also be used. Up to nine locations (one per memory map) may be updated per frame. The multibeam communications package provides a status message indicating whether the uplink control directive was received and has satisfied the checksum correctly. These status messages are normally transmitted on the baseband-processor-mode downlink but again can be derived from the CR&T link. The change from foreground to background memory is accomplished by a single command from the ground.

Memory Map

The baseband processor memory map pairs are made up of two separate memories, each of which consists of either two or three 2K X 8 random-access memory chips. Each half of a memory map pair is controlled by a separate custom large-scale-integrated controller chip called a memory-update controller. Commands to read, write, or request status are sent by the digital routing processor to a memory-update controller chip that is associated with one-half of a

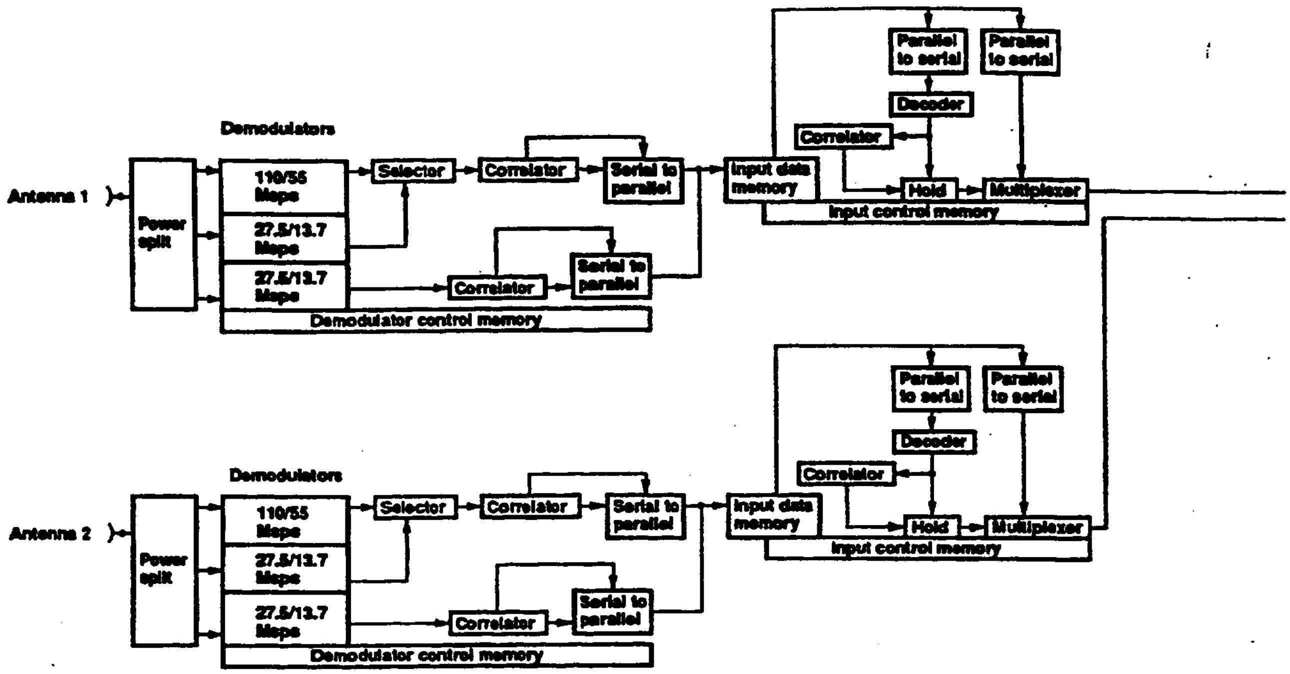


Figure C-2. — Detailed block diagram

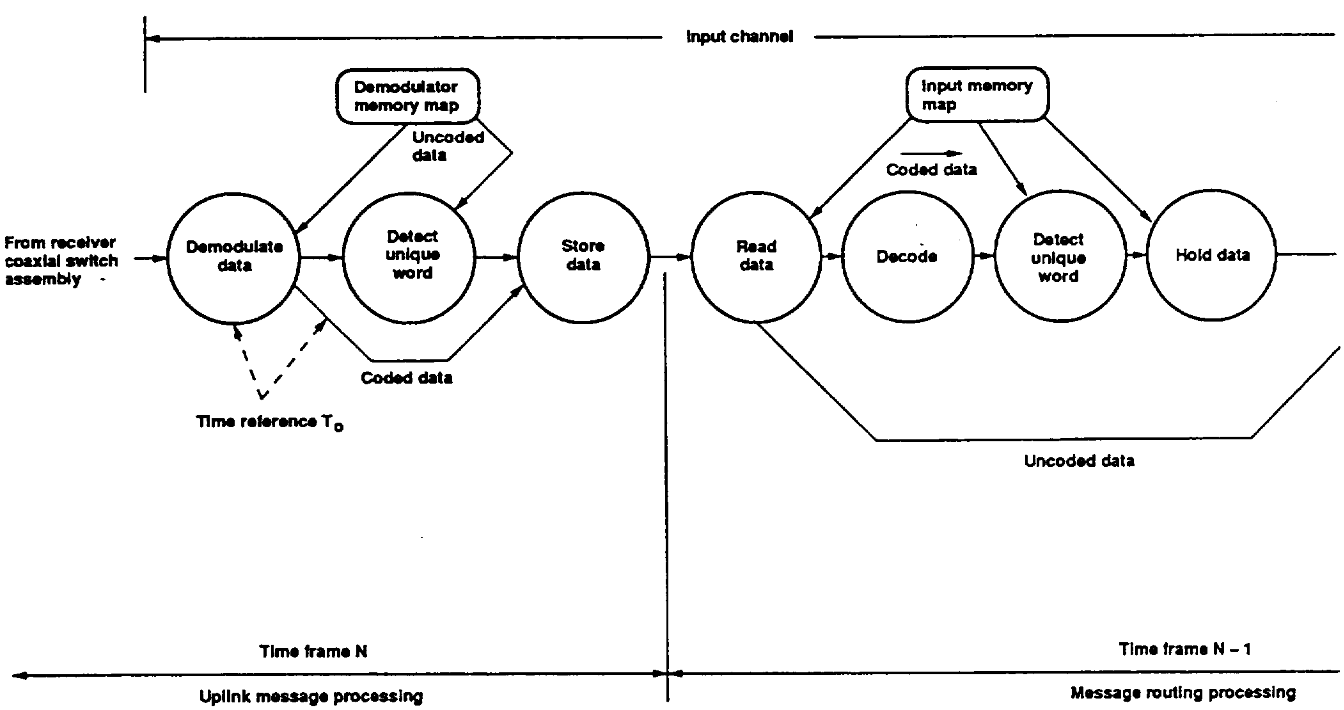
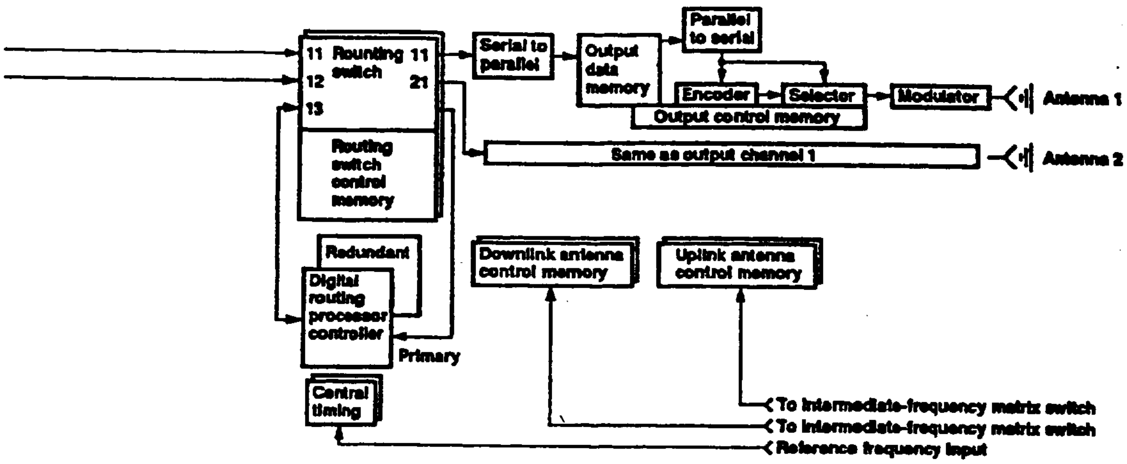
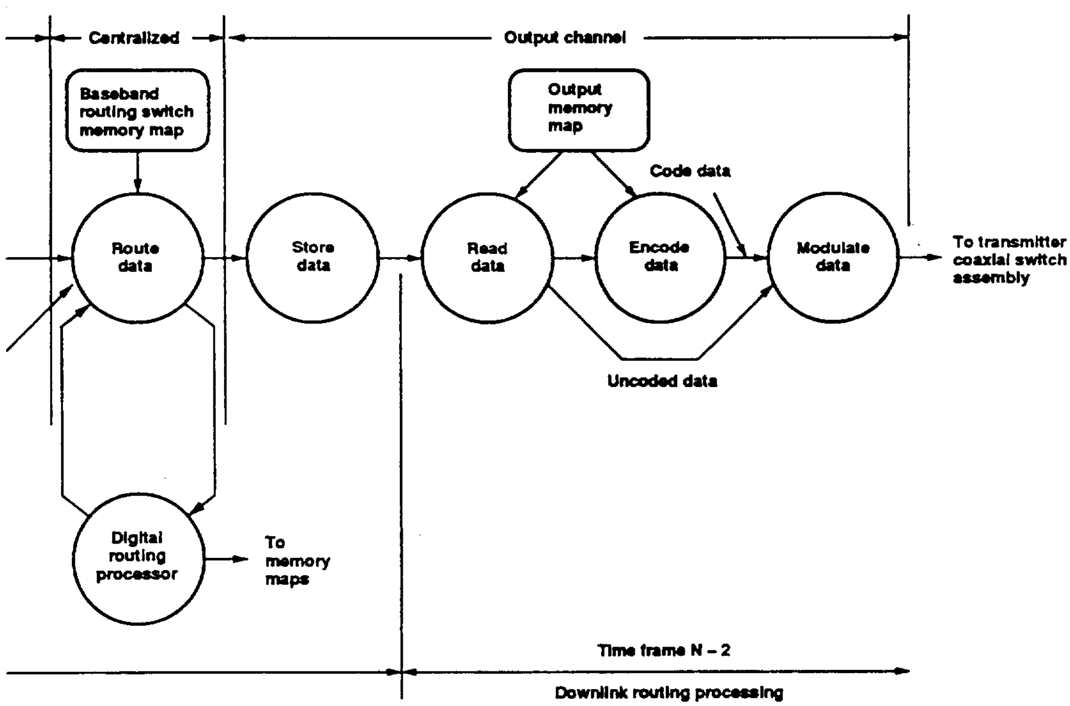


Figure C-3. — Data flow for



of baseband processor.



baseband processor.

memory map pair, rather than to a particular memory map. One memory-update controller in each pair is designated the master, and the other is designated the slave. The master in each pair determines the background/foreground relationship.

Hopping-Beam Antenna Control

All baseband processor traffic utilizes two of four different hopping-beam antennas: the east family receiver uplink, the east family transmitter downlink, the west family receiver uplink, or the west family transmitter downlink. The positions of the spots are controlled by memory map programming in the baseband processor. The control and signal paths are shown in figure C-4.

Position and timing information is contained in the beam control memory maps in the baseband processor. Position data are transmitted to the beam-forming network via the digital control unit portion of the microwave switch matrix. The new beam position is implemented when the timing strobe is received from the baseband processor. The strobe is timed to allow the latest arriving burst in the old dwell position to pass through the beam-forming network before the network switches. The switching will have been completed prior to the earliest arrival of a valid signal in the new dwell. The timing of the signal is measured in the baseband processor by the correlators, which are located after the demodulators.

NORMAL MODE OF OPERATION

Uplink TDMA Frame

Format. - A sample of the uplink TDMA frame is shown in figure C-5. Two parallel paths into the baseband processor are active: one from the east family, and one from the west family. The TDMA frame is periodic with a period of 1 msec.

The frame boundaries are set by the multibeam communications package payload and are acquired by ground users. The multibeam communications package divides the uplink frames into 1728 equal intervals, which are referred to as "slots." One slot represents the minimum unit of time by which a TDMA user may quantize a message. At the maximum data rate of 110.592 Mbps, one slot of data represents 64 bits, for a data throughput of 64 kbps for each complete word or slot.

The uplink frame slots will normally contain three types of data:

(1) Message data - These can include uplink data (either coded or uncoded), commands to the baseband processor, or inbound and outbound orderwires. The length of a message is constrained to satisfy the requirements shown in figure C-5.

(2) Preamble - The uplink bursts must be preceded by a preamble. The preamble is a preprogrammed sequence of bits at least two slots in length that is intended to aid the receiving demodulator in acquiring carrier and bit synchronization, resolving phase ambiguity, and determining word boundaries.

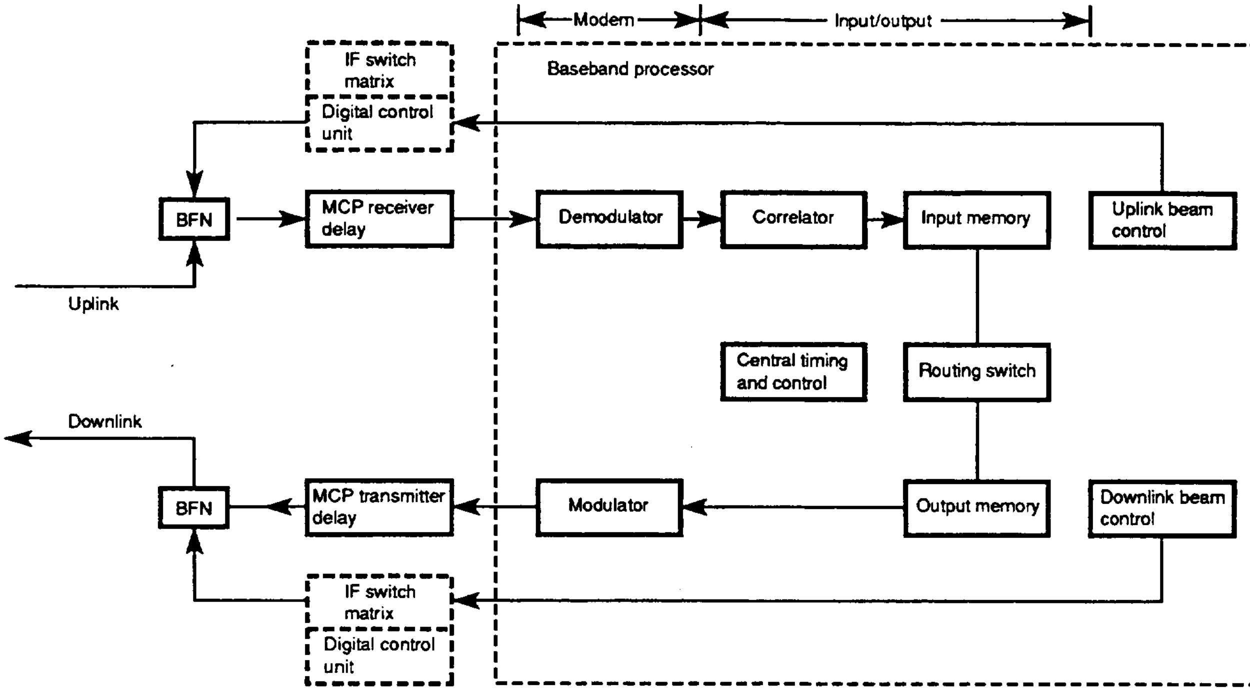
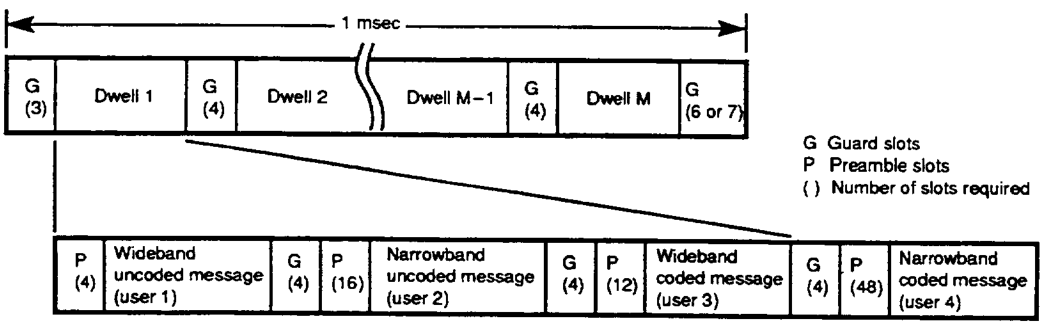


Figure C–4.—Interfaces for scanning antenna beam-forming network.



Message	Data rate, Mbps	Preamble length, slots	Message length,[a] slots	Guard interval length, slots			
				Frame start	Frame end	Between dwells[b]	Following each burst[c]
Wideband uncoded	110.592	4	N	3	7	4	2
Wideband coded	27.648	12	4N + 1	3	7	4	2
Narrowband uncoded	27.648	16	4N	3	6	4	4
Narrowband coded	6.912	48	16N + 4	3	6	4	4

[a] Where N is the number of 64-bit words in message.

[b] Seven slots are needed in the timeshare mode whenever there is a change at scan beams.

[c] Change the guard slot following a wideband burst from 2 to 4 when the next burst is a narrowband burst.

Figure C–5.—Sample uplink frame formats.

(3) Guard slots - These slots are not assigned any information content. This allows blank spots in the TDMA frame to compensate for uplink timing uncertainties and scan antenna switching time. Guard slots at the beginning and end of each frame also allow the baseband processor to reset its memory map pointers.

A sample of the formats to which any baseband-processor-mode uplink frame must conform is shown in figure C-5. In the sample each frame is assumed to consist of M dwell periods, where each dwell period is the time that the hopping-beam antenna is pointed to a fixed location. Each dwell period may consist of multiple bursts originating from multiple users. The number of guard slots required between bursts and dwells is indicated in the figure. If two guard lengths conflict, the larger of the two is required. For example, three guard intervals are required between dwells. Suppose, however, that the last burst in dwell 1 is narrowband. Four guard intervals must then precede dwell 2.

Each burst must begin with a preamble to aid the demodulators in acquiring the uplink signal. Two preambles are used: one for uncoded uplink bursts, and a different one for coded uplink bursts.

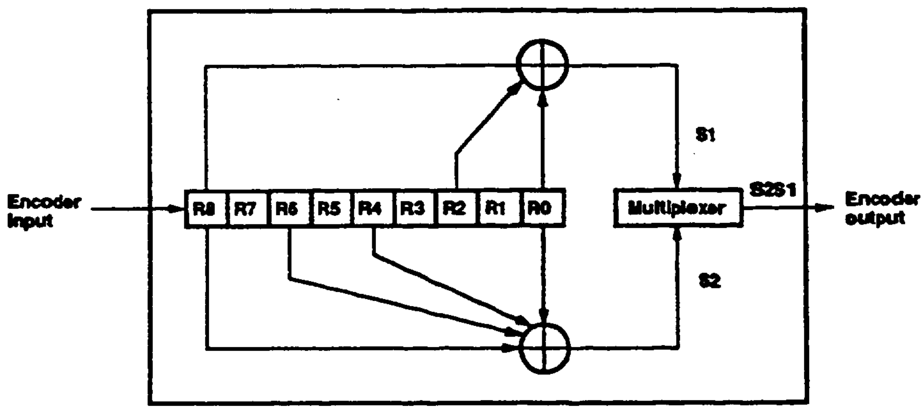
All uplink data and control directives (but not preambles) should be exclusive-OR'd with a scrambler word to ensure the correct number of transitions and the correct one/zero ratio to maintain proper demodulator tracking.

Coding requirements. - The uplink may be coded to improve bit-error-rate performance in the presence of rain fade. Coded operation must also be accompanied by a bit rate reduction to one-quarter of the uncoded rate. The coding algorithm is given in figure C-6. The algorithm consists of two rate-1/2, constraint-length-5 convolutional encoders. The output of the encoders should then be interleaved on a bit-by-bit basis. The encoders are preloaded with zeros. After the message data are clocked through the encoders, a zero word is used to flush the encoders, thereby generating a decoder flush word that is transmitted after the encoded message and used to flush the onboard decoder. This flush word will occupy one slot in mode WL (wideband, low rate) and four slots in mode NL (narrowband, low rate).

The terminology used in describing coded operation is as follows: For coded traffic, each bit of information shifted into the encoder is called an information bit. The encoder is a rate-1/2 encoder, which generates two symbols per information bit, called a symbol pair. Each symbol is demodulated in the baseband processor by using two-bit soft decision (i.e., two bits are generated per symbol; one bit indicates the sign of the symbol, and the other indicates the magnitude (or certainty) of the symbol). Four bits in the baseband processor are routed to the decoder (two bits per symbol, two symbols per symbol pair) to generate the original information bit.

Burst timing. - Each burst received at the baseband processor will have a tracking error word generated by the baseband processor. The uncoded word portion of the preamble is observed and correlated with a stored word to determine whether the burst is early or late. The tracking error word is a 64-bit sequence.

A burst that arrives at or before the assigned arrival time will result in an early tracking error word being generated and stored in the input memory in



Ground terminal forward-error-correcting encoder

1. Initialize registers R1–R8 with zeros.

2. Shift the register contents by one clock cycle as the first bit of the word synchronization/unique word field enters register R8.

3. Generate encoded symbols S1 and S2 according to the feedback circuit connection. S1 should be transmitted first.

4. Repeat steps 2 and 3 until the last information bit of burst is encoded.

Figure C–6. — Uplink coding algorithm.

the position that would have been occupied by the last word of the preamble, if it had been stored. The master control station must program the baseband processor's routing to ensure that the correct tracking error word is provided to each user on the downlink in order to maintain synchronism. The correct tracking error word is determined by the coding flag, which is set by the master control station. A burst arriving late will receive a late tracking error word. An on-time burst is treated as being early. If the demodulator fails to recognize the uncoded word in the window defined in the following table, a no-lock tracking error word is generated.

The early/late code represents the case in which the burst arrival time is early or late by as much as the times indicated in table C-1.

TABLE C-1. - BURST ARRIVAL TIME RANGES

Mode	Early range	Late range
Wideband and narrowband uncoded	1/8 uplink slot time (~72 nsec)	1/8 uplink slot time (~72 nsec)
Wideband coded	2 data bit times (~72 nsec)	3 data bit times (~109 nsec)
Narrowband coded	2 data bit times (~289 nsec)	3 data bit times (~434 nsec)

Downlink TDMA Frame

Format. - The downlink TDMA frame format is similar to the uplink frame format with the following major exceptions:

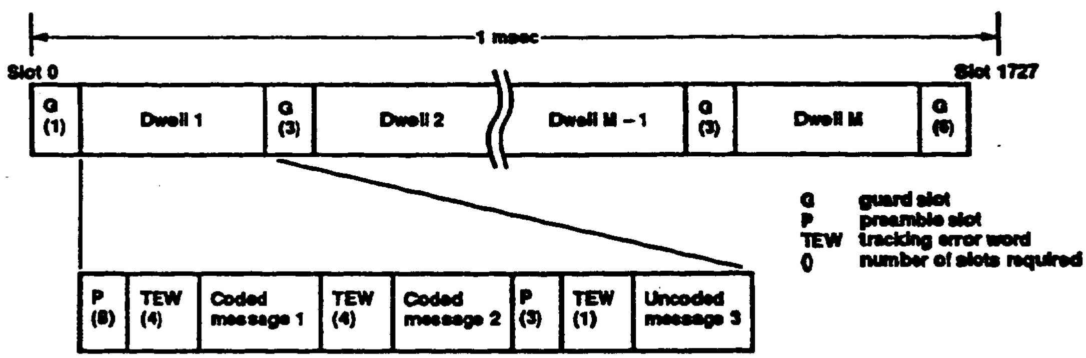
(1) The message data include downlink data (either coded or uncoded), command status words from the baseband processor, or inbound and outbound orderwires. In addition, the master control station will program the multibeam communications package to inject a tracking error word in the downlink for each user in the dwell. This word indicates to each user whether his or her uplink burst is early or late relative to the expected arrival time.

(2) The downlink frame is delayed by 430±15 nsec from the uplink frame.

(3) Since the downlink signal originates from one source (the multibeam communications package), there are no timing variations between data bursts directed to different users (such as can occur in an uplink dwell). If all the messages in a dwell are coded or all the messages are uncoded, a signal preamble will suffice for all users to acquire the signal. When a single dwell contains a mixture of coded and uncoded bursts, there must be one preamble for each type.

A sample downlink frame format is shown in figure C-7; it includes a table of the constraints for any baseband-processor-mode downlink frame. A more detailed diagram is included for a select dwell that was arbitrarily chosen to contain both coded and uncoded data.

Each downlink burst must be preceded by a preamble. Two preambles will be stored in the baseband processor for downlink transmission: one for coded



Message	Data rate, Mbps	Tracking error word length, slots	Preamble length, slots	Message length, slots	Guard interval length, slots		
					Frame start	Frame end	Between dwells
Uncoded downlink	110.592	1	3	N	1	6	3
Coded downlink	27.648	4	8	4N	1	6	3

[a] Where N is the number of 64-bit words in message.

Figure C-7. — Sample downlink frame format.

traffic, and one for uncoded traffic. If a dwell is to receive both coded and uncoded traffic, both preambles must be used.

Coding requirements. - The coded downlink traffic will also be transmitted at one-quarter the rate for the uncoded traffic. The encoder used is a rate-1/2, constraint-length-5 convolutional encoder. Symbol rate reduction by one-half provides the additional traffic rate reduction.

OTHER MODES OF OPERATION

General Description

The multibeam communications package's baseband processor will normally operate in one of the following four modes:

(1) Initiation
(2) Acquisition
(3) Digital routing processor self-test
(4) Normal

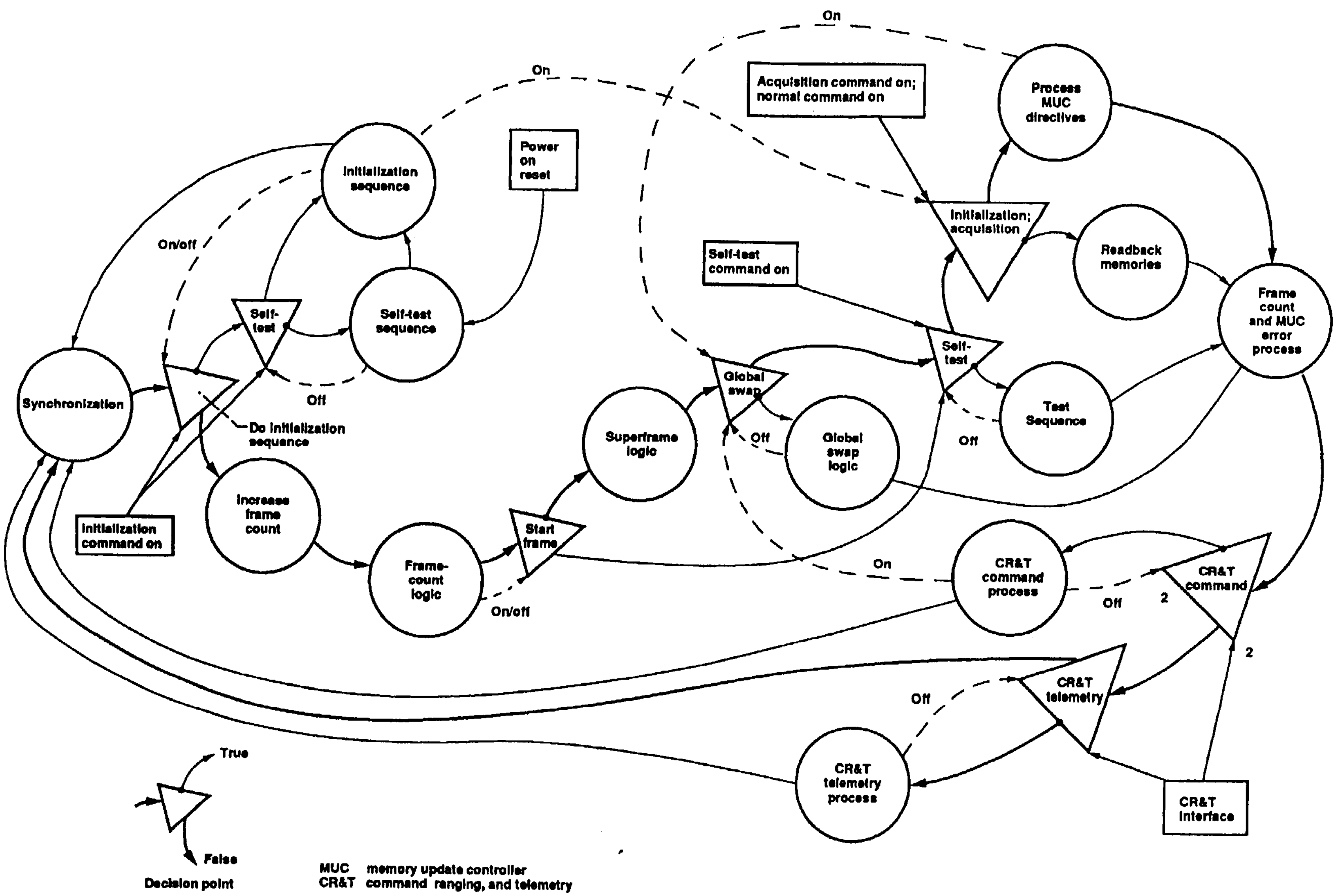
The normal mode was described earlier. The other modes are described in this section, along with the method of transition between modes.

Figure C-8 shows the executive control flow for the digital routing processor software. The path corresponding to the normal mode of operation is emphasized. Figure C-8 indicates that when the baseband processor is first powered up, the initialization mode is entered. In this mode the digital routing processor performs self-tests and initializes memories. The initialization mode is automatically terminated by the digital routing processor, and then the baseband processor enters the acquisition mode. While the baseband processor is in the acquisition mode, the NASA ground station can verify initial memory map loading and acquire uplink and downlink spacecraft time references. An uplink command causes the baseband processor to enter the normal mode of operation as described in the section "Normal Mode of Operation." As indicated in figure C-8 the initialization mode can be reached from the normal mode or the acquisition mode via the initialization-mode discrete pulse command. The acquisition mode can be reached directly from the normal mode of operation via the acquisition-mode discrete pulse command. The self-test mode will normally be entered from either the normal or the acquisition mode as a result of the self-test-mode discrete pulse command.

Initialization Mode

The initialization mode is designed to allow the NASA ground station to acquire the transmitting and receiving frame times. The digital routing processor will enter the initialization mode either upon initial power-on or upon receipt of the initialization discrete logic pulse command.

The initialization mode will take up to 20 sec to complete. During this time the digital routing processor will neither process any uplink commands nor format downlink status. At the completion the baseband processor will automatically enter the acquisition mode. The digital routing processor (DRP) will update the DRP-mode status field of the 32-bit accumulated memory-update controller



MUC memory update controller
CR&T command ranging, and telemetry

Figure C-8. — Executive control flow for digital routing processor.

error flag in the serial telemetry word to indicate the end of the initialization mode and the start of the acquisition mode.

Acquisition Mode

The baseband processor will enter the acquisition mode automatically upon completion of the initialization sequence or upon receipt of the acquisition-mode discrete pulse command.[2] This mode is essentially the normal mode with the following exceptions:

(1) The baseband processor will not process BBP-mode uplink control directives. The commands will be routed to the command buffer in the digital routing processor; however, they will not be processed. Memory map updates can be processed by using the serial command link.

(2) The control directive status words will not be generated from BBP-mode uplink control directives. The DRP status buffers will contain background memory map contents generated by "read current address" commands sent to the memory-update controllers by the digital routing processor. The current address register in the digital routing processor used to address successive background memory locations will be set to all zeros and incremented each frame. The register will be reset every 1728 frames.

This mode is usually used to allow the NASA ground station to acquire the spacecraft time reference. In addition, however, during a troubleshooting mode the acquisition-mode discrete pulse command can be sent to cause the baseband processor to enter a memory dump mode and allow dumping of memory maps via the baseband-processor-mode downlink.

Digital Routing Processor Self-Test Mode

The digital routing processor self-test mode will be initiated only by receipt of the mode's discrete pulse command. The command may be received in either the normal or the acquisition mode. Sending the command during the initialization mode will cause the digital routing processor to reinitiate the initialization-mode sequence and the baseband processor to recompute the programmable read-only memory (PROM) checksum and to update the PROM checksum status words.

The self-test will be completed in less than 5 sec and will cause the baseband processor to return to the mode it was in before the test. While a self-test command is being executed, control directives and CR&T commands received by the digital routing processor will be ignored.

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[2]On startup the NASA ground station must acquire the spacecraft before entering the normal mode.

ACQUISITION MEMORY MAP CONFIGURATION

The initial memory map configuration includes two uplink bursts and two downlink bursts. The two uplink bursts are the control burst and the transmitting acquisition burst. The downlink bursts are the inbound orderwire burst and the receiving acquisition burst. All four bursts will be coded. The uplink and downlink frame formats are shown in figure C-9. The initial memory map configuration of the baseband processor will result in the received data being routed as shown in figure C-10.

The initial configuration will configure the wideband demodulators and the input memories in both the west and east families (baseband processor input ports 1 and 2, depending upon configuration of the WIRS and the RCSA); however, only bursts received via port 1 will be routed; therefore the multibeam communications package's receiving channel must be configured to route the west beam family to port 1. If the wideband demodulator connected to port 1 fails, the routing switch will need to be reconfigured via the CR&T link before the beam is acquired by the NASA ground station.

Control Burst

The control burst is positioned to start at the beginning of the frame. Note that in order to configure the hopping-beam antennas to point at Cleveland on time to receive a burst at slot 1, the antenna data and strobe must be set prior to the end of the previous frame. The control burst is intended to serve as the control burst in the normal mode as well and includes nine coded words for uplink control directives and three coded words for the OBOW. The control directives will be decoded and routed to the digital routing processor but will not be processed. The OBOW messages will be decoded and then reencoded as part of the receiving acquisition burst and sent down the baseband-processor-mode link. The control directive slots will be routed to the digital routing processor from input port 1.

Transmitting Acquisition Burst

As shown in figure C-9 the baseband processor will configure the input wideband demodulators to receive a coded burst, and received data will be decoded and routed through the baseband routing switch.

Receiving Acquisition Burst

The baseband processor will configure the modulators to downlink a signal that will contain a coded burst preamble for the NASA ground station to acquire the receiver timing. The burst format will be as indicated in figure C-9 and will contain coded data only. The data contained in the burst will be routed by the baseband routing switch as shown in figure C-10. The digital routing processor shown in this figure controls the baseband routing switch, which does the actual routing. The tracking error word contained in the receiving acquisition burst will indicate the relative timing of the transmitting acquisition burst. The NASA ground station can use this information to acquire uplink timing.

Control burst (CB) / Transmitting acquisition burst (TAB)

Uplink frame	Guard time	Pre-amble	Baseband processor control directive	Outbound orderwire message	Guard time		Guard time	Pre-amble	Acquisition message number (inbound orderwire)	Guard time
Number of slots	2	8	36	12	1	1644	1	8	8	8
Slot number	0–1	2–9	10–45	46–57	58	59–1702	1703	1704–1711	1712–1719	1720–1727

Orderwire burst / Receiving acquisition burst

Downlink frame	Guard time	Pre-amble	Tracking error word (CB)	Baseband processor status message	Inbound order-wire message	Decoder flush bits		Pre-amble	Acquisition burst identification	Outbound order-wire message	Tracking error word (TAB)	Acquisition message number (inbound orderwire)	Decoder flush bits	Guard time
Number of slots	1	8	4	40	8	4	1615	8	4	12	4	8	4	8
Slot number	0	1–8	9–12	13–52	53–60	61–64	65–1679	1680–1687	1688–1691	1692–1703	1704–1707	1708–1715	1716–1719	1720–1727

Reference burst

	Pre-amble	Tracking error word (UTB or CB)	Outbound orderwire message	Tracking error word and traffic	Decoder flush bits
Number of slots	8	4	12	4 x n	4

Traffic burst: either uncoded (UTB) or coded (CTB)

Preamble	Inbound orderwire message	Traffic

Figure C-9. — Baseband processor acquisition formats.

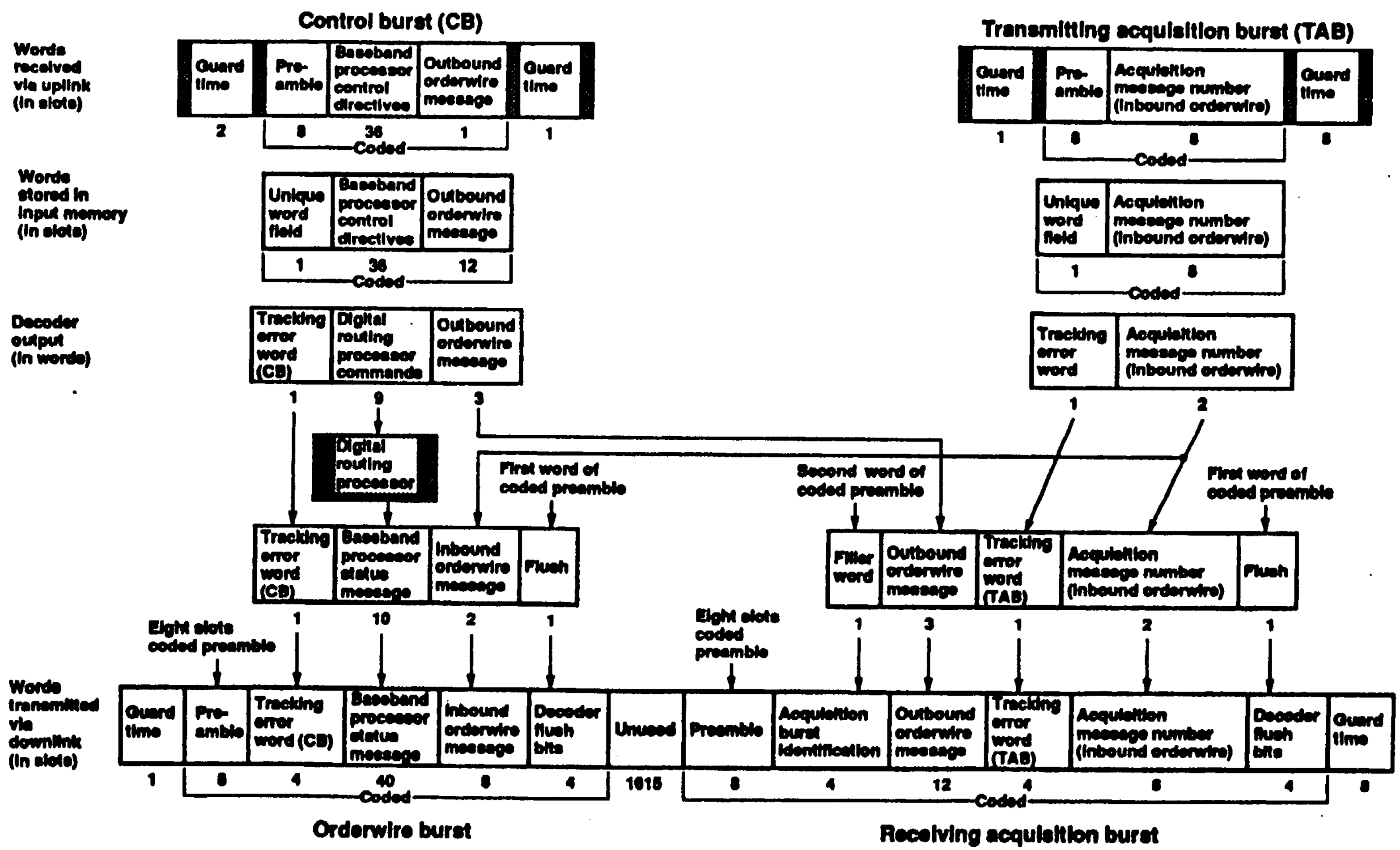


Figure C-10. — Initial acquisition data flow.

Orderwire Burst

The baseband processor will configure the modulators to output the orderwire burst with the format and frame position that it would use in the normal mode. The burst will contain the information indicated in figure C-9. The downlink will be coded and contain the following information:

(1) The tracking error word that contains timing information for the control burst.

(2) Ten words of baseband processor status message. The first nine words normally contain uplink control directive status words. In the acquisition mode, however, the baseband processor will read each of the memory maps and downlink the contents sequentially by using the status message slots. The last word of the status message will contain the frame count and the error status word.

(3) Ten words of digital routing processor self-test results. The first word will contain the results of the PROM checksum verification. The second word will contain the flag register status, which represents the state of the memory-update controller's error flags. The remaining eight words will be central processing unit random-access memory status words. Note that in normal operation there may not be a need to downlink all 10 status words. The baseband processor can be programmed to reduce the number of status words either in the acquisition mode via CR&T or in the baseband-processor-mode uplink control path during the normal mode.

(4) Two words of inbound orderwire message.

MEMORY MAPS

Definition of Memory Map

The baseband processor contains a different memory map to control each of the following nine functions:

(1) Control of the 110- and 27.5-Mbps demodulators corresponding to intermediate-frequency input port 1
(2) Control of the 110- and 27.5-Mbps demodulators corresponding to intermediate-frequency input port 2
(3) Read sequence for input port 1 input data memory
(4) Read sequence for input port 2 input data memory
(5) Control of the baseband routing switch. Two memory maps are included: one controlling the primary switch, and one controlling the redundant switch
(6) Read sequence for output port 1 output data memory
(7) Read sequence for output port 2 output data memory
(8) Uplink hopping-beam antenna switching sequence and strobe timing bit. Two memory maps are included: one active when the primary control processor is enabled, and one active when the redundant control processor is enabled.
(9) Downlink hopping-beam antenna switching sequence and strobe timing bit. Two memory maps are included: one active when the primary control

processor is enabled, and one active when the redundant control processor is enabled.

Each memory map contains up to 24 bits of data per register location. The memories consist of either two or three 2K X 8 random-access memories each, providing a possible 2K locations, of which 1728 are used. Each location corresponds to one slot in the TDMA frame. Memory maps are always accessed sequentially, with the data contained in location N typically being read out of memory and implemented in slot N + 1.

Demodulator Control Memory Maps

The demodulator memory maps control which, if any, of the demodulators is active at a particular slot time within a frame. In addition, they contain bits that control the timing of functions used by the demodulators to acquire carrier and data signals and to resolve carrier ambiguity.

Input Control Memory Map

The memory map controlling the input data memory defines the sequence by which the data are read out. In addition, it controls the routing of data to the convolutional decoder and the timing of the correlator following the decoder.

Routing Switch Control Memory Map

The routing switch control memory map contains the routing sequence that controls the path data follow when routed through the baseband routing switch. The switch allows data to be routed to each of the output ports from any of the input ports. Data from one input port can be routed to several output ports, but no more than one input port can be routed to one output port.

There are three baseband routing switch input ports. They are distinct from the baseband processor input ports, although data received via baseband processor input port 1 are routed through baseband routing switch input port 1 and data received via baseband processor input port 2 are routed through baseband routing switch input port 2. Baseband routing switch input port 3 is connected to the digital routing processor status buffer, allowing command status words, downlink preamble words, and self-test status words to be routed to the downlink path. There are also three baseband routing switch output ports. Ports 1 and 2 service baseband processor output ports 1 and 2, respectively, and port 3 allows command words received via the baseband processor uplink to be routed to the digital routing processor.

Output Control Memory Map

The map controlling the output memory serves much the same purpose as the map controlling the input memory, that is, to allow data to be read out of the memory in a random sequence under program control. It also controls routing of data to the convolutional encoders.

Uplink Scan Antenna Sequence Control Memory Map

The uplink hopping-beam antenna control memory map contains data that control the timing and sequence that the hopping-beam antennas follow during a frame.

Downlink Scan Antenna Sequence Control Memory Map

The downlink hopping-beam antenna control memory map functions exactly as the uplink hopping-beam antenna control memory map, except that the timing of the trailing edge is different.

Rules for Configuring Memory Maps

As indicated previously, there are nine different memory maps in the baseband processor. These nine maps comprise five different types:

(1) Demodulator control
(2) Input control
(3) Routing switch sequence control
(4) Output control
(5) Hopping-beam antenna sequence control

A different set of rules is used to program each of these types.

Memory Map Updates

Processing of the baseband processor traffic will conform to the foreground memory map contents and will therefore be cyclic with a period of 1 msec. The 1-msec intervals or frames are grouped into superframes. The superframes consist of 75 frames. As the traffic requirements change, the background memory maps can be updated via the orderwire (see section "Baseband-Processor-Mode Message Processing") or the CR&T uplink (see section "Comparison Between CR&T Link and Baseband Processor Processing"). The new configuration will be implemented when a foreground/background memory map swap is commanded. In order for all Earth terminals to know in which frame to expect a memory map swap, the swap will always occur at a superframe boundary.

BASEBAND-PROCESSOR-MODE MESSAGE PROCESSING

Uplink Control Directives and Downlink Status Messages

The baseband-processor-mode link is the primary path for updating the control memories from the NASA ground station and receiving status and frame-count messages from the baseband processor.

Updating control directives via baseband-processor-mode uplink. - The uplink control directives will normally be transmitted once at the beginning of the frame in a single coded burst called the control burst, as indicated in figure C-9. Updating memory locations via the baseband processor uplink, however, need only be in accordance with the following rules:

(1) The control directives may be uplinked in any order and in any number of bursts. They will always be coded.

(2) The control directives cannot be routed to the digital routing processor during the first 64 slots of a frame.

(3) Up to nine control directives may be routed to the digital routing processor every frame. It is valid to program the digital routing processor to route no control directives, although this would require any commands to be sent via the command link. Slots allocated for control directives but not used should be filled with no-operation directives in the baseband-processor-mode uplink to ensure that random noise does not accidentally get into the digital routing processor. (The digital routing processor will normally insert no-operation control directives into the command buffer when fewer than nine control directives are configured.)

(4) The nine control directives cannot include more than one command directed to each control memory. For example, if a memory-update control directive was followed by a read-memory-location control directive during the same frame and directed to the same memory map, the baseband processor would discard the first directive and execute only the last one received. On the other hand, if a routing switch memory location is written to, the "read status register 0" control directive can be sent and will be executed if it is directed to the foreground memory, since the write directive must be directed to the background memory.

Transmitting status messages via downlink. - The downlink is the primary path for providing status messages from the baseband processor.

The downlinked status words are normally transmitted via a single coded burst, called the orderwire burst, to the NASA ground station. These status words can be routed down to the ground in any order and in any number of bursts provided that the following rules are taken into account:

(1) The status words cannot be routed to the output data memory from the digital routing processor at a rate exceeding one word every 16 routing slot times.

(2) The status words must be routed from the command/status buffer in the order in which the digital routing processor writes them. A subset of the status buffer can be routed, but a word can be routed only after all words stored ahead of it are routed.

(3) The status words in the command/status buffer are written by the digital routing processor in a specific order.

Timing of Control Directives and Command Status Words

Command status words will be issued according to the following guidelines:

(1) When a memory-update controller chip executes a command or control directive, a 44-bit status word is created indicating the results of performing that function.

(2) The status word remains in the memory-update controller until another command is received. At that point the status word from the previous command is sent out.

(3) If a command is sent to the spacecraft via the command link, the status word created by the memory-update controller will be sent down via telemetry. If a control directive is received via the uplink, the created status word will be routed to the digital routing processor's command/status buffer so that it can be routed via the baseband-processor-mode downlink.

The result of these guidelines is that during normal operation when nine control directives are transmitted to the multibeam communications package via the uplink and nine status words are returned, at least one extra frame delay is introduced by the memory-update controller between control directive received and status word transmitted.

COMPARISON BETWEEN CR&T LINK AND BASEBAND PROCESSOR PROCESSING

The baseband processor can be commanded via the CR&T uplink as well as the baseband-processor-mode uplink. The major differences between the two are summarized below:

(1) The function and the format for all serial commands are the same as those described in the section "Baseband-Processor-Mode Message Processing" except that the serial command will be received by the multibeam communications package in four 16-bit command words. (The convention used in this document is that four 16-bit command words make up one 64-bit command.)

(2) Although the function and format of serial command status words are also the same as those for the baseband processor's downlink control directive status words, other baseband processor status words and CR&T telemetry words are different.

(3) The command rate sent via the CR&T link is much lower than those sent via the baseband-processor-mode uplink. Serial commands are received at a rate of 200 16-bit words every 2 sec. This means that commands may be sent to the baseband processor at a maximum rate of 50 commands per second.

(4) The command status messages cannot be read as fast as commands are transmitted. The serial telemetry words are read one 8-bit word every 2 sec. Therefore it requires 16 sec to receive a command status word.

(5) The serial commands and serial telemetry are not scrambled and do not involve any error correction codes at the multibeam communications package level. Any error detection and correction must be performed before the signal reaches the command and telemetry processor unit.

SECTION D

MICROWAVE SWITCH MATRIX MODE OF OPERATION

DESCRIPTION

The 3- to 4-GHz four-by-four microwave switch matrix includes crossbar architecture and is controlled by the digital control unit of the multibeam communications package. Microwave matrix crosspoint control is accomplished by using field-effect-transistor switching devices. Input power routing and output recombining are accomplished by using recursive couplers. The digital control unit is commanded directly through the command link in the microwave switch matrix mode. This unit processes and stores the matrix configuration sequence data and controls the 16 switch modules as well as the antenna hopping beams. The four-by-four switch architecture is packaged as a planar unit; shielded compartments within one housing are used for each input and output port. This results in a compact design and also provides high circuit isolation. Figure D-1 shows the intermediate-frequency matrix switch configuration.

MATRIX SWITCH MODULE

The baseline approach to implementing the matrix switch module uses a two-stage, field-effect-transistor switch hybrid. This two-stage radiofrequency amplifier consists of two field-effect-transistor pairs, where one device per pair provides the switching function. Figure D-2 shows a diagram of one switch amplifier.

The field-effect-transistor switching amplifier circuitry consists of two radiofrequency stages, bias stabilization circuits, and a very low-current driver circuit. Two identical single-stage amplifiers are cascaded with input and output pads to improve circuit matching and to reduce gain ripple. Isolation is improved by packaging radiofrequency stages in hybrid modules. A simple biasing scheme provides temperature stability and rebiases the drain and input radiofrequency gate in the off state to provide maximum isolation. The bias circuit also minimizes off-state current. This is very significant in a large switch matrix, where the number of off-devices is much larger than the number of on-devices. The driver circuit only uses radiation-hardened components, is extremely fast, and requires little drive current and minimum bias current. The characteristics of the switches are tabulated in table D-1.

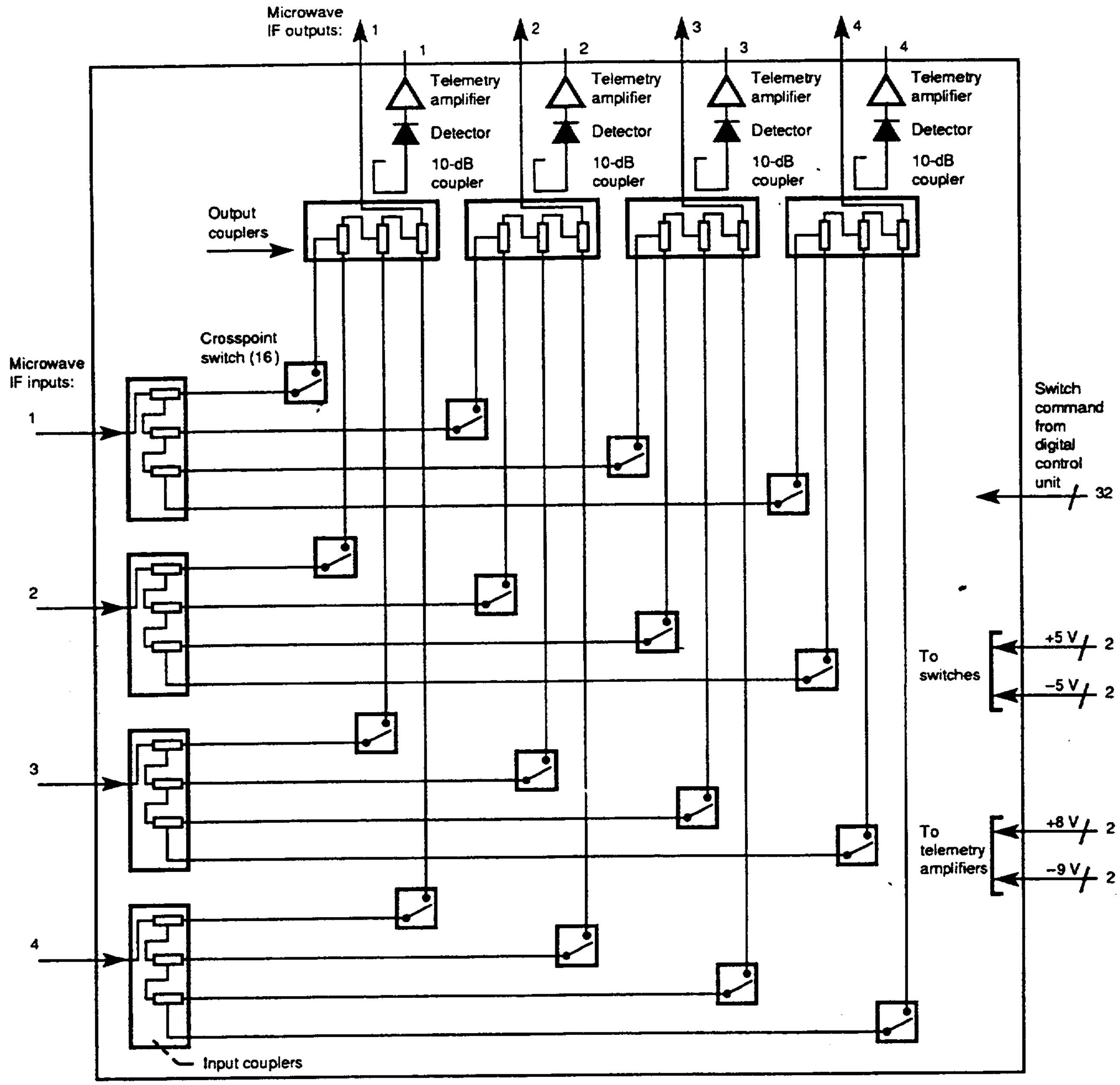


Figure D–1.—Block diagram of intermediate-frequency matrix switch (radiofrequency portion).

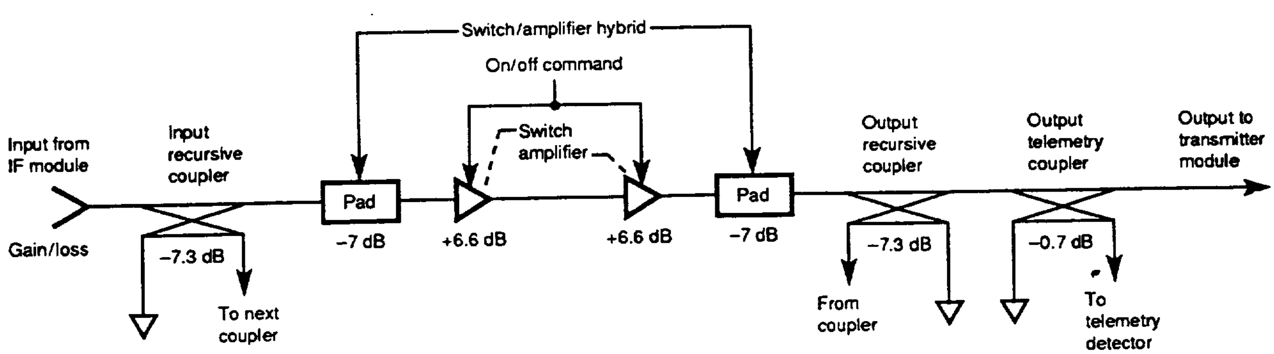


Figure D–2.—Block diagram of switch amplifier.

TABLE D-1.—CHARACTERISTICS OF MICROWAVE SWITCH MATRIX

Characteristic	Range, limit or quantity
Intermediate-frequency input	
Number of ports	4
Frequency range, GHz	3.00 to 4.06
Input power level, dBm ± dB	-0.7 ± 2.0
Voltage standing-wave ratio:	
Source	≤3.0:1
Input (for any input ports and any allowed switch state)	≤1.6:1
Maximum no-damage input level, dBm	15
Intermediate-frequency output	
Number of ports	4
Frequency range, GHz	3.00 to 4.06
Output power level, dBm ± dB	-20.7 ± 3.0
Voltage standing-wave ratio:	
Load	≤1.8:1
Output (for any output port and any allowed switch state)	≤1.6:1
Intermediate-frequency characteristics	
Gain, dB	-20 ± 1
Isolation (ratio of on/off attenuation), dB	-50
Gain flatness (peak-to-peak across passband), dB	1
Passband, GHz	1.06
Phase linearity, deg:	
Peak-to-peak phase nonlinearity	≤4
Peak to peak/5 MHz (frequency range, 3.1 to 3.8 GHz)	≤0.3
Recommended operational bandwidth (1 dB), MHz	800
Intermediate-frequency switch functions	
Allow any input port to be interconnected with any output port, including the broadcast mode, in which a single input can be interconnected with as many as three output ports	Yes
Switch state (min.), μsec	1
Switch time, nsec	≤100

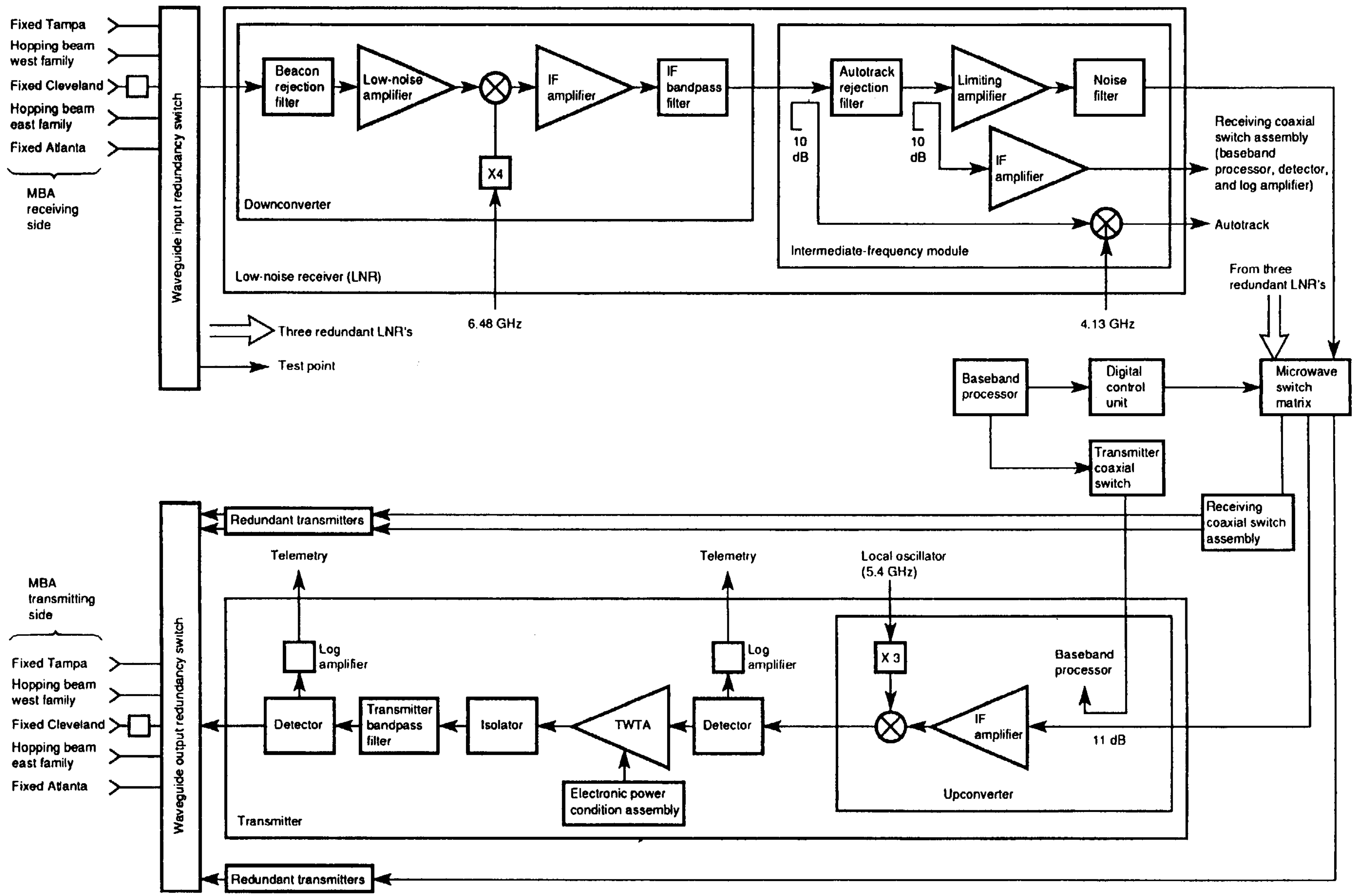


Figure D-3.—Microwave switch matrix signal paths (one shown).

SIGNAL ROUTING

Four low-noise receivers feed the inputs to the microwave switch matrix. Figure D-3 shows a function diagram of a typical receiver. Traffic is routed to the receiver input from the receiving side of the multibeam antenna via the WIRS. The receiver front end first amplifies uplink traffic signals through a state-of-the-art low-noise amplifier and then downconverts them to the 3- to 4-GHz band. The uplink frequency is in the 29- to 30-GHz band. Portions of the second module are diverted to other functions via 10-dB couplers. The main signal goes through an intermediate-frequency limiting amplifier and is then conditioned by the noise filter before entering the switch matrix. The noise figure of the receiver is less than 5.0 dB.

The four outputs of the switch matrix are connected to four transmitters. After being amplified, the traffic signals are upconverted to the downlink frequency as shown in figure D-3. The downlink frequency is amplified and its power level adjusted to meet the requirements of the TWTA's. These amplifiers will operate at an output power level of 46 W. The outputs are conditioned by the transmitter bandpass filters and input to the transmitting side of the multibeam antenna via the WORS. An important operational consideration to note is that the limiting amplifiers are noise limited and hard limited. Also, the TWTA's are operated at their saturated maximum output limits.

The waveguide redundancy switches permit the interconnection of the five antenna ports in a variety of configurations to the four low-noise receivers on the one side and the four transmitters on the other side. The positions of the switches illustrated in figure D-4 are configured via the command link and remain static during the timeframe of a particular experimental period.

OPERATING MODES

The 900-MHz, 1-dB bandwidth transmission channels provide different options for modulation techniques, ranging from frequency-division multiple access to frequency-division-multiplexed single channel per carrier to various modulation techniques in TDMA modes using binary or quaternary phase-shift keying, and possibly 16-quadrature amplitude modulation techniques. The 900-MHz bandwidth was determined analytically on the spacecraft's end-to-end performance. The geographic areas to be covered are limited by the coverage capabilities of the multibeam antenna, the steerable antenna, or both. The details of the antenna coverages are provided in section A, "Flight System Technology."

Take note that although the switch matrix is a four-by-four configuration, the system is designed to operate by using only three signal paths at any one time through the switch. The fourth path provides redundancy. The microwave switch matrix has two operating modes: static and dynamic. The static mode is the simpler of the two. Describing the static mode first makes some features of dynamic mode operation more easily understood.

Static

The static mode of operation uses the microwave switch matrix in a fixed configuration in which no changes are performed for a period covering the length of the experimental test. This could be several minutes or several days. Where one or both of the beam-forming network families is a part of the network configuration, the beam-forming network would be "frozen" for the duration of the test.

In the static mode the waveguide redundancy switches and the switch matrix can be configured in various ways, providing point-to-point communication or broadcast (point to multipoint) communication.

Dynamic

The ability of the switches in the matrix to turn on or off in 100 nsec or less enables the use of efficient switching in satellite-switched TDMA (SS/TDMA) traffic. As in the static mode various interconnections are possible when using the switch matrix.

The method of modulation used with the switch matrix is not a constraint, but the modulation method must be synchronized to the switching operation of the switch. In order to provide a synchronous signal to the Earth terminals, a "blink" state is provided at every superframe boundary. The blink state can range from 1 to 100 μsec but cannot exceed 100 μsec. The "blink" is a momentary pause in which all the switches in the matrix are turned off. The timing functions are explained here.

The switch matrix is controlled by the digital control unit. The unit also controls the beam-forming network of the hopping-beam portions of the multibeam antenna. The unit performs the following command and telemetry functions:

(1) Receives four 16-bit serial command words to form a 64-bit memory-update instruction to write to one background memory location.
(2) Receives one 16-bit serial command word to control the unit configuration.
(3) Cycles through memory and forms eight 8-bit serial telemetry words to indicate the contents of each active background memory location.

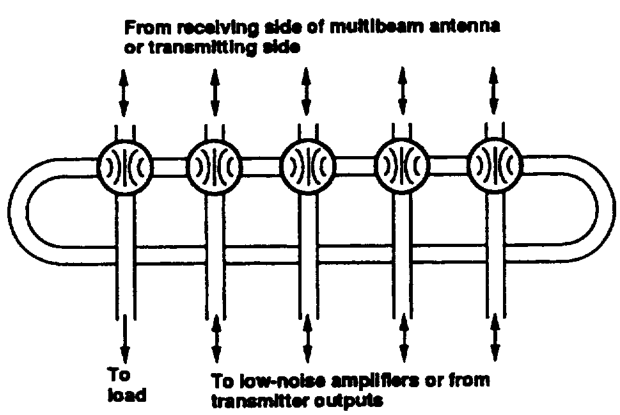


Figure D-4. — Diagram of waveguide redundancy switches.

APPENDIX A - ACRONYMS

ACTS	Advanced Communications Technology Satellite
AMCE	antenna-mounted communications electronics
AMT	ACTS mobile terminal
ASP	attitude system processor
BBP	baseband processor
BFN	beam-forming network
BPSK	binary phase-shift keying
CMOS	complementary metal oxide semiconductor
CONUS	continental United States
CR&T	command, ranging, and telemetry
DAL	Dallas, Texas
DAMA	demand-assigned multiple access
DCU	digital control unit
D/C	downconverter
DEN	Denver, Colorado
ECL	emitter-coupled logic
EIRP	effective isotropic radiated power
FDM	frequency-division multiplexing
FDMA	frequency-division multiple access
HBR	high bit rate
HOU	Houston, Texas
IBOW	inbound orderwire
IF	intermediate frequency
KC	Kansas City, Kansas
LA	Los Angeles, California
LBR	low bit rate
LET	link evaluation terminal
LNR	low-noise receiver
MBA	multibeam antenna
MCP	multibeam communications package
MEM	Memphis, Tennessee
MIA	Miami, Florida
MOSAIC	Motorola oxide self-aligned implanted circuits
MSM	microwave switch matrix
NO	New Orleans, Louisiana
NV	Nashville, Tennessee
OBOW	outbound orderwire
PCM	pulse code modulation
PHX	Phoenix, Arizona
QPSK	quaternary phase-shift keying
RCSA	receiving coaxial switch assembly
RF	radiofrequency
SEA	Seattle, Washington
SF	San Francisco, California
SMSK	serial minimum-shift keying
TCSA	transmitting coaxial switch assembly
TDM	time-division multiplexing
TDMA	time-division multiple access
TT&C	telemetry, tracking, and command
TWTA	traveling-wave tube amplifier
U/C	upconverter

USAT	ultra-small-aperture terminal
VSAT	very-small-aperture terminal
WIRS	waveguide input redundancy switch
WORS	waveguide output redundancy switch
WS	White Sands, New Mexico

APPENDIX B - BEACONS

INTRODUCTION

A feature of ACTS is its ability to adjust for adverse atmospheric conditions by using burst rate reduction and encoding (forward error correction, or FEC) of its digital communications signals. This adaptive feature enhances the reliability of the communications link during rain fades and provides maximum efficiency during clear weather.

Beacons are provided onboard the spacecraft at 20.2 and 27.5 GHz for monitoring uplink and downlink signal fades. The beacon signals can be used to analyze the effects of rain, atmospheric disturbances, and other propagation phenomena. As was mentioned in section A (under Spacecraft Bus—Command, Ranging, and Telemetry Subsystem) the 20.2-GHz beacons are also used to transmit telemetry information from the spacecraft to the NASA ground station.

ACTS COMMAND, RANGING, AND TELEMETRY SYSTEM OVERVIEW

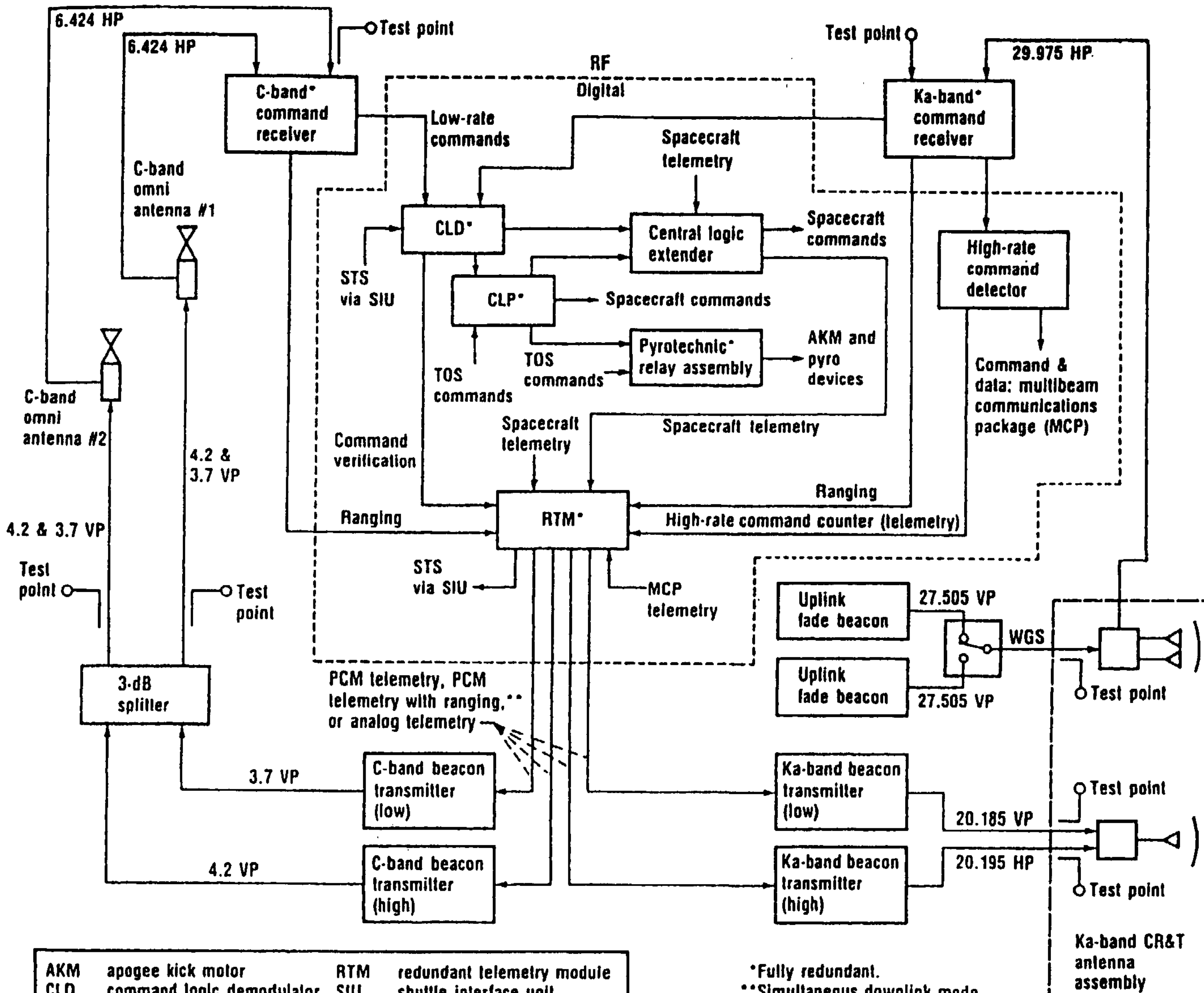
The beacons are part of the command, ranging, and telemetry subsystem. A general overview of this subsystem is presented first, and then detailed beacon information is presented to assist an experimenter in determining the link budget for an experiment using the beacons. The command, ranging, and telemetry (CR&T) subsystem (fig. AB-1) can be divided into three functional areas. Two of the areas operate at radiofrequencies (RF), and one operates at baseband.

The two RF systems comprise C- and Ka-band receivers and transmitters. C-band commands are transmitted throughout the transfer and drift orbit phase after satellite launch and when placing the satellite into geosynchronous orbit. C-band communications are also used at geosynchronous altitudes should the Ka-band CR&T link become disabled. Typically, the Ka-band CR&T link is used during everyday operations after the spacecraft is deployed and on station.

The digital baseband portion, which is indicated within the dashed line, performs the command, ranging, and telemetry processing. This system is divided functionally between the low-rate commands and the high-rate commands. The low-rate spacecraft bus commands control the positioning and attitude of the satellite. The high-rate commands control the normal operations of the communications payload. Only the Ka-band CR&T subsystem can control the operations of the communications subsystem.

The downlink telemetry data are compiled by the redundant telemetry module. The redundant telemetry module generates subcarriers at 14.5, 19, or 27.8, unmodulated 32, and 64 kHz. The types of information riding on these subcarriers are analog telemetry, digital pulse-code-modulated (PCM) telemetry (e.g., temperature readings and voltage levels), ranging, and command verification.

The beacon antennas provide coverage to the continental United States (CONUS) and are located on the face panel of the satellite (fig. AB-2). The 20.2-GHz reflector is the smaller of the two and measures approximately 11 by 6.5 in.; the 27.5-GHz reflector is approximately 13 by 7.5 in. Both are configured



AKM	apogee kick motor	RTM	redundant telemetry module
CLD	command logic demodulator	SIU	shuttle interface unit
CLP	central logic processor	STS	Space Transportation System
HP	horizontal polarization	VP	vertical polarization
PCM	pulse-code modulated	WGS	waveguide switch

*Fully redundant.
**Simultaneous downlink mode (Ka band only).

Figure AB-1.—Function block diagram of CR&T subsystem. (All frequencies are in gigahertz.)

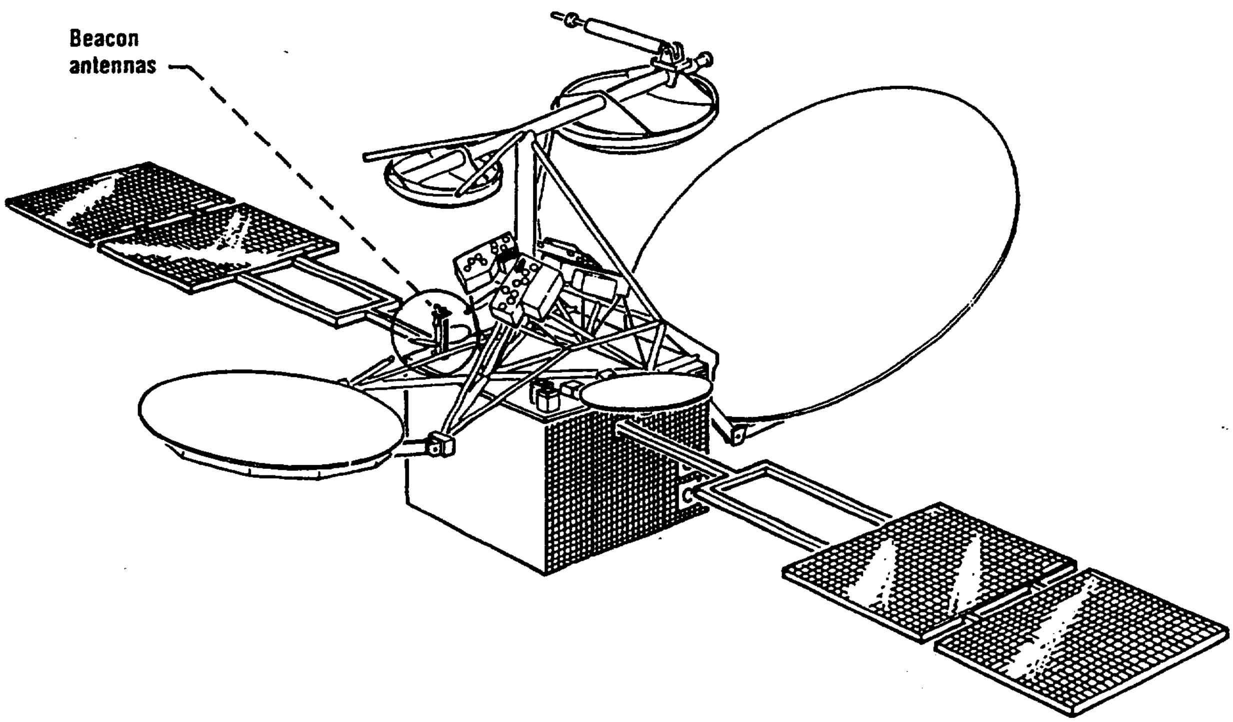


Figure AB-2.—Location of beacon antenna assembly on Advanced Communications Technology Satellite.

in an elliptical offset fashion. The beacon antenna assembly in figure AB-3 shows the two reflectors and their offset rectangular feeds.

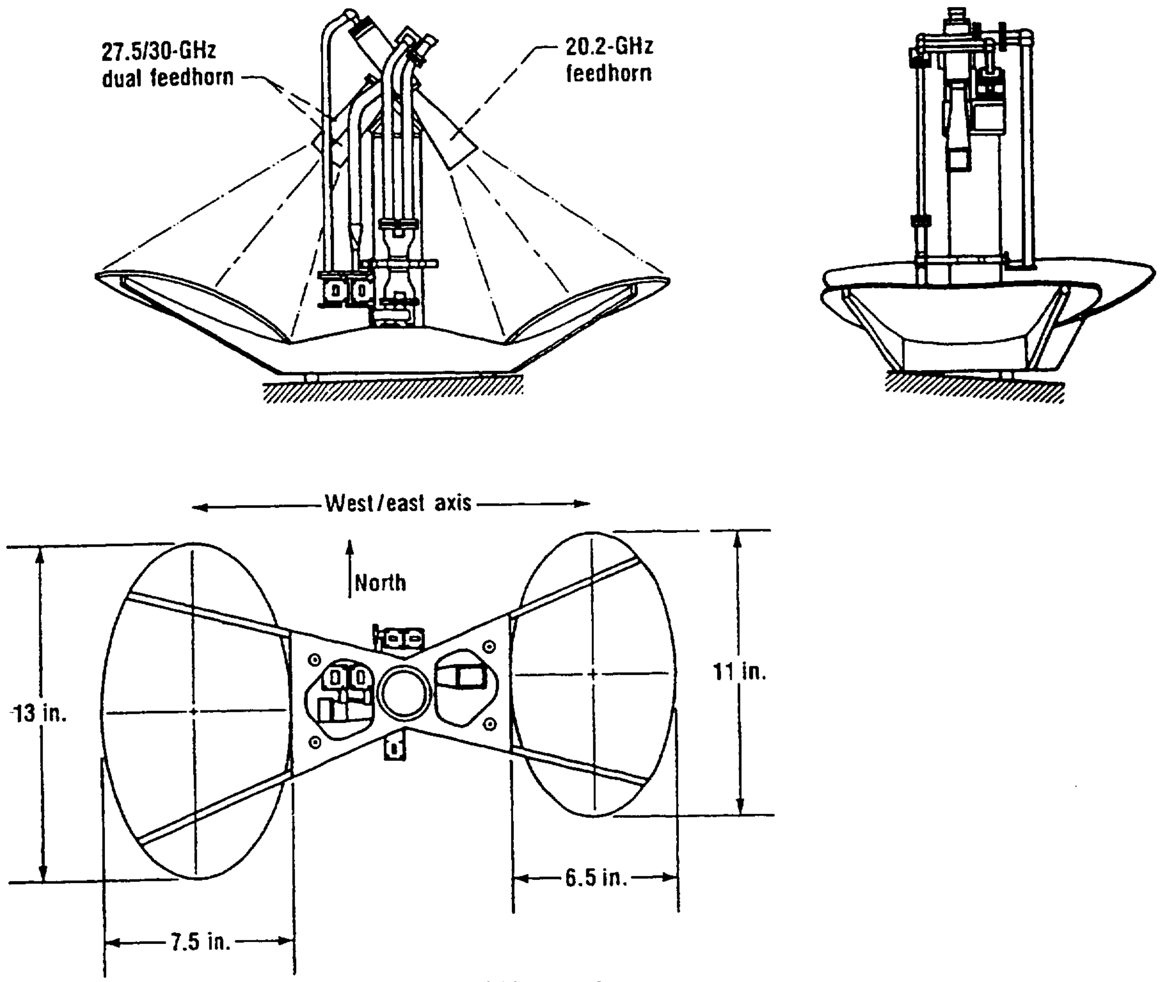
The two 20.2-GHz (downlink frequency) beacon signals are cross-polarized to each other. Only one of two signals is usually present. The large reflector transmits at 27.5 GHz and receives at 30 GHz (uplink frequencies). These transmitted and received signals are also cross-polarized.

KA-BAND (ON-STATION) BEACON CHARACTERISTICS AND FREQUENCIES

In the normal mode of operation one of the 20.2-GHz beacon carrier signals will be modulated by the 32- and 64-kHz subcarriers. The 32-kHz subcarrier is used as a placeholder in the subcarrier PCM and PCM dwell modes and is unmodulated. It is used to maintain the power of the modulated carrier at the same level as in the simultaneous ranging/PCM mode, which is approximately 3 dB below the unmodulated carrier level. The 64-kHz subcarrier carries the PCM telemetry from the spacecraft bus (housekeeping) and the multibeam communications package (MCP) and also carries command verification data. Fade measurements at the downlink frequency (20.2 GHz) are practically unaffected by the beacon modulation in the operational telemetry modes or by the contents of the telemetry data.

In geosynchronous orbit the Ka-band telemetry beacons will be phase modulated in one of the following modes. The occupied signal bandwidth will be from 10 to 100 kHz. The modulation levels have been set to provide constant power in the carrier central line.

Mode	Description
1. Two subcarriers, one at 32 kHz and the other at 64 kHz	The 64-kHz subcarrier is modulated to a peak deviation of $\pi/2$ radian with 1024-bps PCM data in a biphase-L format. The 32-kHz subcarrier is unmodulated, serving as a power placeholder when ranging is not active. The two subcarriers each cause a peak carrier phase deviation of 0.72 radian ±10 percent, and they are linearly combined.
2. A frequency-modulated 14.5-kHz subcarrier with a peak deviation of 1.088 kHz	The subcarrier is modulated with analog data that has been band limited by using a 220-Hz low-pass filter. The subcarrier will cause a 1.0±0.1-radian peak phase deviation of the carrier.



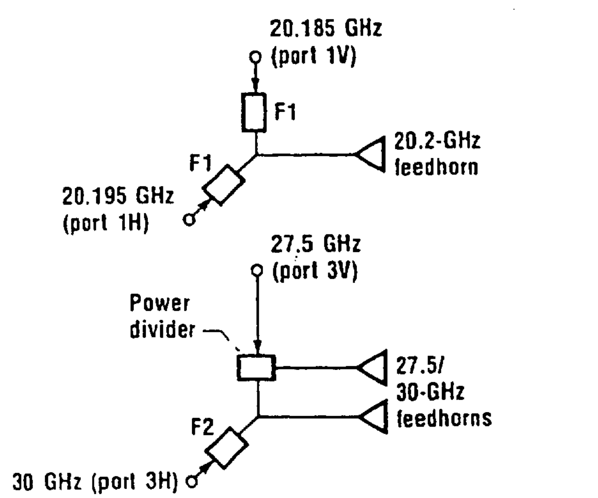
(a) Layout of antenna.

Filter requirements for meeting baseline specifications:

F1—40-dB minimum suppression of 27.5- to 30.6-GHz band

F2—35-dB minimum rejection of 27.5 GHz

Port isolation (ports 1V-1H)— ≥ 35-dB isolation in 20.18- to 20.20-GHz band



(b) Block diagram of feed assembly.

Figure AB-3.—Diagrams of Ka-band CR&T antenna.

3. A sequence of ranging tones with values of 35.4 Hz, 283.4 Hz, 3968.2 Hz, and 27.777 kHz

The three lower frequency tones are frequency modulated on a 19-kHz subcarrier with a deviation of 1 kHz. Both the 27.777- and 19-kHz tones are approximately square waves. The ranging tones will cause a 0.50±0.05-radian peak phase deviation of the carrier. Simultaneously, PCM telemetry is provided on the 64-kHz subcarrier, as in mode (1). The 32-kHz subcarrier is not present in this mode.

Tables AB-I and AB-II present the frequency and modulation data, as well as other characteristics of the 27.5-GHz beacon and the two 20.2-GHz beacons. Table AB-III provides beacon phase noise information.

TABLE AB-I.—CHARACTERISTICS OF BEACON SIGNALS

Characteristic	Uplink fade beacon (27.5 GHz, unmodulated carrier)	Downlink telemetry beacons (20.2 GHz, modulated carrier)
Carrier frequency at beginning of life, GHz ± MHz	27.505 ± 0.5	20.185 ± 0.3 (VP) 20.195 ± 0.3 (HP)
Measured beacon frequencies from box and subsystem testing of flight hardware, GHz	UFB1 - 27.504973 UFB2 - 27.505028	KBL - 20.185013 KBH - 20.194897
Frequency stability at any one temperature over -10 to 42 °C, ppm	(a)	(a)
Operating temperature, °C	-5 to 36	-5 to 39
Minimum RF power at end of life, dBm	19.0	22.5
Maximum output power stability, dB	±1 over 24 hr; ±2 over 2 yr	±0.5 over 24 hr; ±1.5 over 2 yr
Minimum effective isotropic radiated power for fade measurements, dBW	15.5	17.5

[a]±10 over 2 yr; 4 peak to peak in 24 hr.

TABLE AB-II.—FREQUENCY AND MODULATION DATA FOR DOWNLINK BEACON SUBCARRIERS

[FM = frequency modulation.]

Subcarrier type	Modulation frequency, kHz	Peak deviation	Data rate, bps
Pulse-code-modulated (PCM) telemetry			
Unmodulated[a]	32	--------	----
Biphase-L phase-shift keyed[b]	64	1.57 rad	1024
Analog telemetry (FM direct)	14.5	1.1 kHz	----
Ranging tones[c]			
FM subcarrier[d]	19	1 kHz	----
FM direct	27.777	1 kHz	----

[a]Replaces ranging tones to keep carrier power constant.
[b]Contains housekeeping, multibeam communications package, and command verification data.
[c]Low-frequency ranging tones modulate 19-kHz subcarrier; high-frequency ranging tone modulates 27.777-kHz subcarrier.
[d]Tones from 35 Hz to 4 kHz.

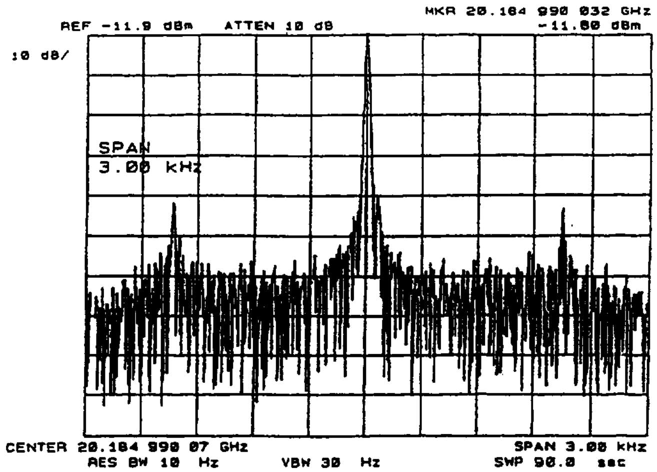
TABLE AB-III.—BEACON PHASE NOISE

Frequency away from carrier, Hz	Phase noise, dBc/Hz[a]	
	Uplink fade beacon (27.5 GHz)	Downlink beacons (20.185 or 20.195 GHz)
50	-49	-51
100	-58	-61
200	-65	-68
300	-69	-72
400	-73	-76
1 000	-76	---
3 000	-80	---
10 000	-92	-92

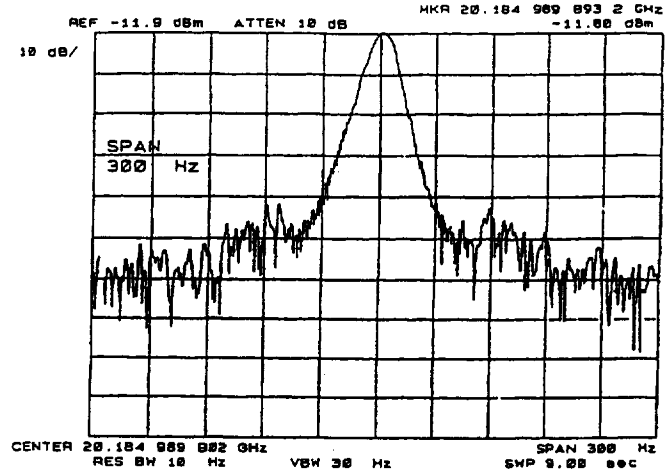
[a]dBc/Hz = decibels referenced to carrier power level in 1-Hz bandwidth.

SPECTRAL PLOTS

Various spectral plots for the primary modes of the telemetry beacons are presented in figures AB-4 to AB-7. These plots were made during box and subsystem testing of flight hardware at Martin Marietta Astro-Space. Plots during normal operations, presented in figures AB-4 and AB-5, show the main

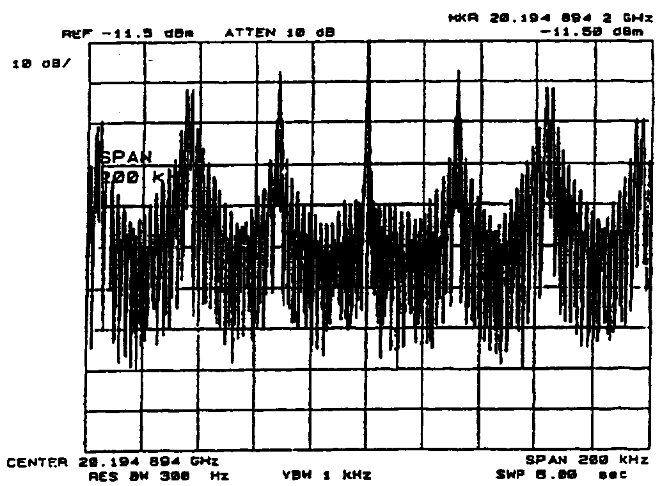


(a) RTM 2, PCM operational, 3 kHz span.

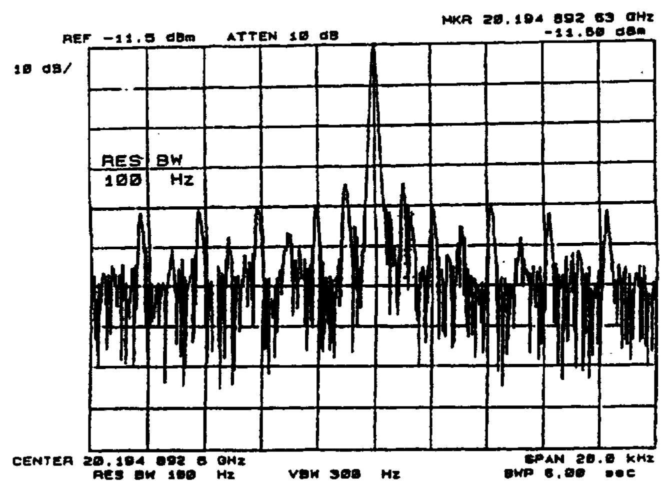


(b) RTM 2, PCM operational, 300 Hz span.

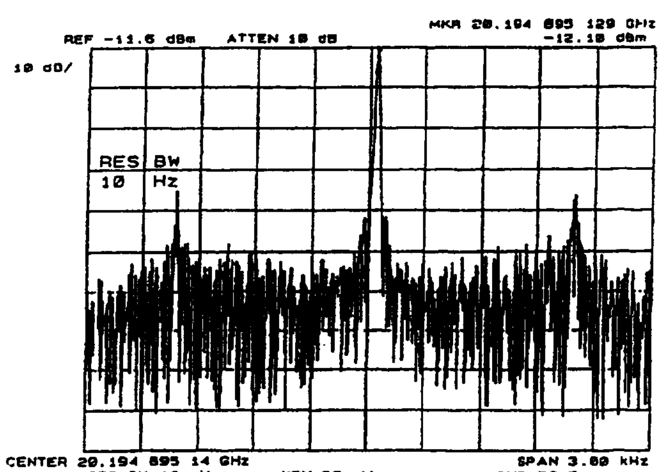
Figure AB-4.—20.185 GHz (KBL) beacon spectral plots.



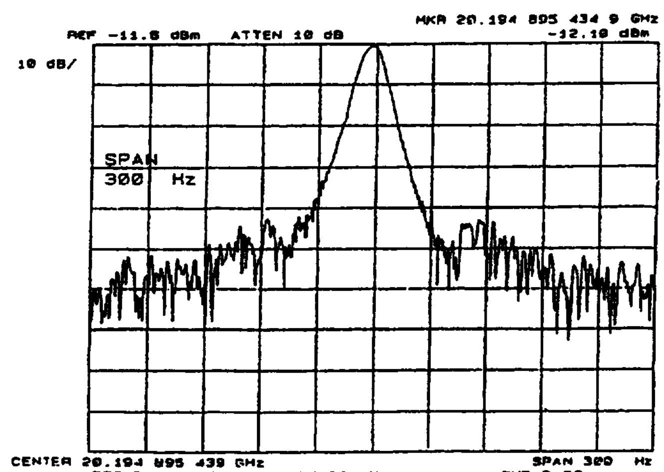
(a) RTM 1, PCM operational, 200 kHz span.



(b) RTM 1, PCM operational, 20 kHz span.



(c) RTM 1, PCM operational, 3 kHz span



(d) RTM 1, PCM operational, 300 Hz span.

Figure AB-5.—20.195 GHz (KBH) beacon spectral plots.

carrier and the resulting sidebands from the PCM. Figures AB-4(a) and (b) show the 20.185-GHz beacon, which is also referred to as the "Ka-band low," or KBL beacon, at spans of 3 kHz and 300 Hz, respectively. Figures AB-5(a) to (d) show the 20.195-GHz beacon, which is referred to the "Ka-band high," or KBH beacon, at spans of 200 kHz, 20 kHz, 3 kHz, and 300 Hz, respectively.

Ranging will be conducted four days per week for a period of approximately 5 min every 2 hr. It will be conducted at predetermined times so that it can easily be correlated with any glitches observed in fade measurements. During ranging the 32-kHz subcarrier is replaced with the 27.8-kHz ranging tone approximately 54 sec of each minute. Three spectral responses of the Ka-band high (20.195 GHz) beacon during this mode are shown in figures AB-6(a) to (c) at spans of 200 kHz, 3 kHz, and 300 Hz, respectively. During the remainder of the ranging period (i.e., about 6 sec of each minute), the 19-kHz subcarrier, which contains the three low-frequency tones, modulates the carrier. Only one tone will be transmitted at a time.

Fade measurements at the uplink frequency (27.5 GHz) are undisturbed by modulation, but they are available only for the vertical polarization. Figures AB-7(a) and (b) are spectral responses of the 27.5-GHz beacon, referred to as the "uplink fade beacon" (UFB) at spans of 200 kHz and 3 kHz, respectively.

LINK BUDGET CALCULATIONS

Table AB-IV provides the formulas and maximum losses of carrier power resulting from beacon modulation.

TABLE AB-IV.—REDUCTION OF UNMODULATED CARRIER POWER DUE TO PHASE MODULATION

(a) Formulas

For single subcarrier or tone loss:

$$\text{Loss} = -20 \log[J_0(\theta)]$$

For two subcarriers or tone losses:

$$\text{Loss} = -20 \log[J_0(\theta_1)J_0(\theta_2)]$$

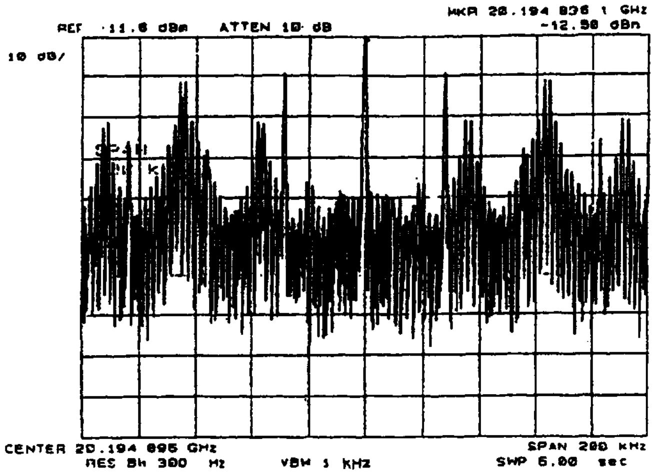
where $J_0(\theta)$ is the zero-order Bessel function of the first kind and θ, θ_1, and θ_2 are the radian modulation indices.

(b) Carrier power losses

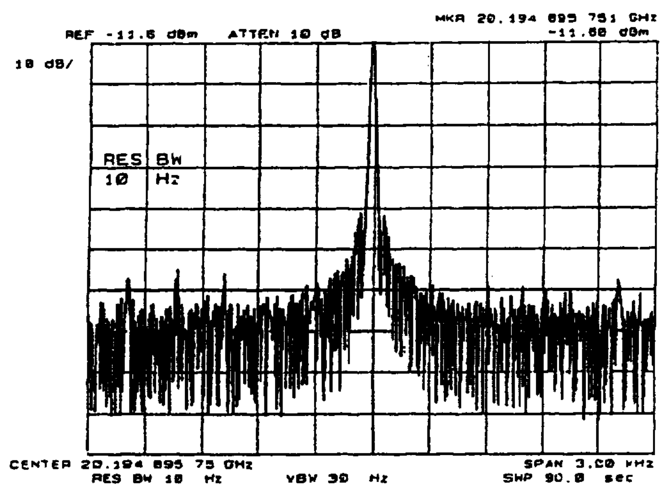
Source of modulation	Number of subcarriers	Peak deviation, rad	$J_0(\theta_i)$	Maximum modulation loss, dBc[a]
Ranging	1	1.1	0.72	-2.9
Analog telemetry	1	1.1	0.72	-2.9
Pulse-code-modulated telemetry	2	0.83 each	0.835 each	-3.1
Ranging or PCM	2	0.525, 0.83	0.932, 0.835	-2.2

[a]dBc = decibels referenced to carrier power level.

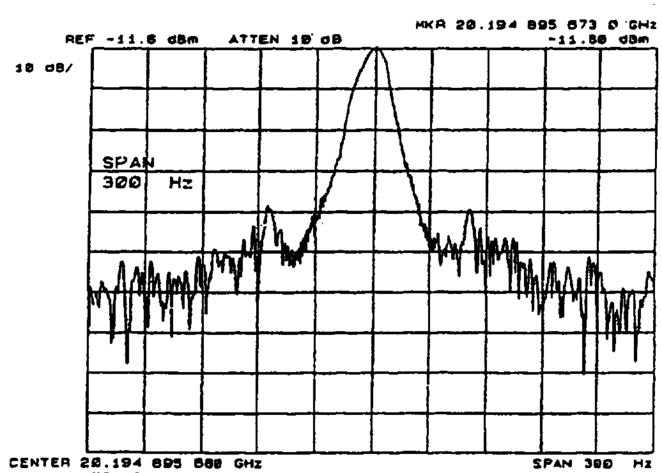
Figure AB-8 shows the transmitter antenna gains for the continental United States.



(a) 200 kHz span.

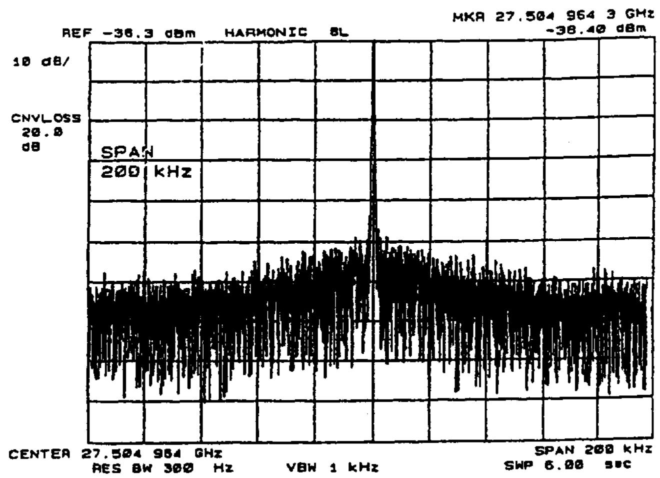


(b) 3 kHz span.

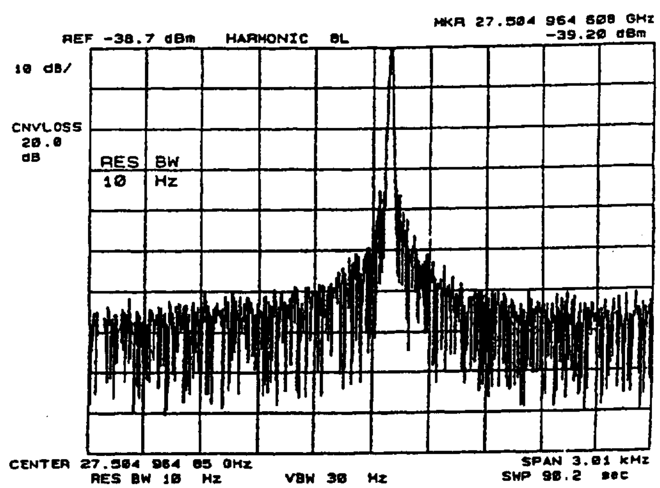


(c) 300 kHz span.

Figure AB-6.—Spectral response - 20.195 GHz with simultaneous ranging (RTM 1, 27.7 kHz ranging tone, PCM).



(a) 200 kHz span.



(b) 3.01 kHz span.

Figure AB-7.—Spectral response - (27.5 GHz UFB 1).

By using standard geometric relationships, the user can compute the range to his or her receiver. Once the range L is known, the free-space loss can be computed from the equation

$$L_{fs}(\mathrm{dB}) = 20 \log \left(\frac{4\pi LF}{c} \right)$$

where

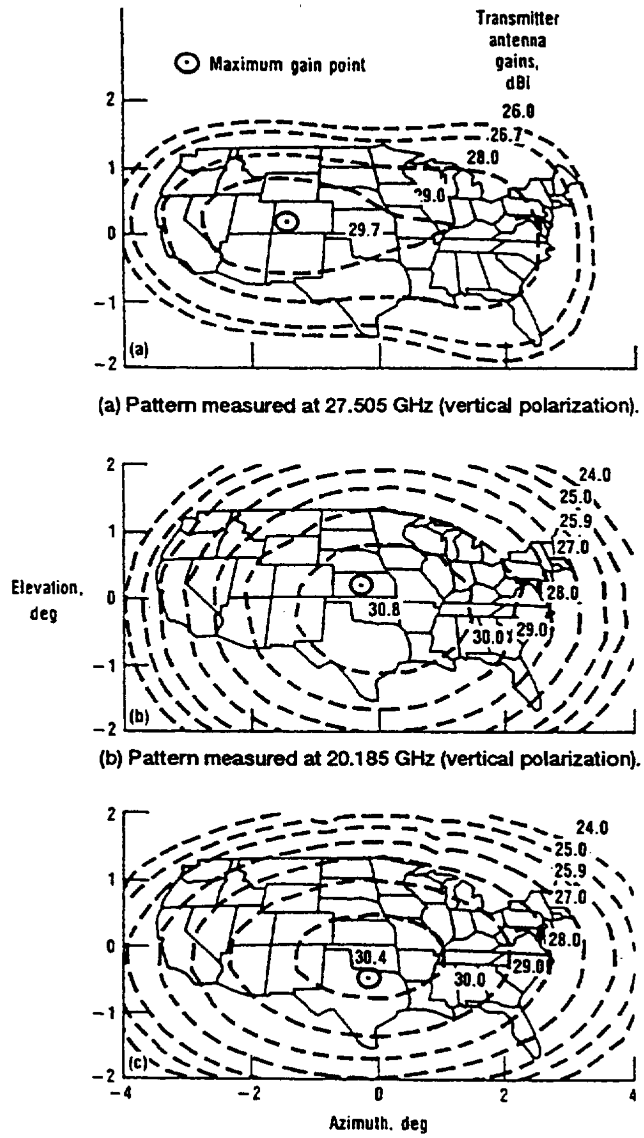
L distance from satellite to Earth terminal

F carrier frequency

c speed of light

The necessary parameters can now be determined in calculating a link budget specific to an experimenter's site. The beacon frequency and the power level are obtained from table AB-I, the modulation losses from table AB-IV, and the transmitter antenna gain from figure AB-8. The received power level at the experimenter's location can be obtained from the range equation. Further details of link calculations can be found in any textbook on satellite communications.

Table AB-V contains the downlink budgets for the beacons at the nominal edge of CONUS coverage, with the exception of the first column, which provides data at the master control station in Cleveland, Ohio. The frequency used for telemetry and ranging and fade measurements is 20.2 GHz.



(a) Pattern measured at 27.505 GHz (vertical polarization).

(b) Pattern measured at 20.185 GHz (vertical polarization).

(c) Pattern measured at 20.195 GHz (horizontal polarization).

Figure AB-8.—Uplink fade beacon and Ka-band beacon transmitter radiation patterns of Ka-band CR&T antenna assembly. Satellite longitude, 100° W; antenna boresight: longitude, 96.4° W; latitude, 35.9° N; azimuth, −0.495°; elevation, −5.897°.

TABLE AB-V.—Ka-BAND DOWNLINK BUDGETS

Parameter	Telemetry and ranging (NASA ground station)	20.2-GHz fade	27.5-GHz fade
Beacon transmitter power (end of life, 2-yr values), dBW	-7.50	-7.50	-10.00
Coupling and cabling loss, dB	-0.80	-0.80	-0.90
Antenna gain, dBi	27.90	[b]25.90	[b]26.80
Minimum satellite EIRP, dBW	[a]19.60	[b]17.60	[b]15.90
Free-space (path) loss, dB	-210.10	-209.90	-212.60
Rain loss, dB	-9.00	(c)	(c)
Atmospheric loss, dB	-0.40	-0.40	-0.60
Polarization loss, dB	-0.10	-0.20	-0.10
Ground station pointing loss, dB	-0.20	-0.20	-0.40
Ground station gain/noise temperature (G/T), dBi/K	26.70	19.10	20.00
Boltzmann constant, dBW/K-Hz	-228.60	-228.60	-228.60
Received carrier power/noise power density, C/N_o, dBW	55.10	54.60	50.80
Modulation loss, dB	-----	-3.1	0.0
Required C/N_o density (PCM), dB-Hz	51.00	(d)	(d)
System margin, dB	4.10	(d)	(d)
Required C/N_o density (analog), dB-Hz	49.60	(d)	(d)
System margin, dB	5.50	(d)	(d)
Required C/N_o density (ranging), dB-Hz	51.10	(d)	(d)
System margin, dB	4.00	(d)	(d)

[a]EIRP level at Cleveland, Ohio.
[b]Minimum EIRP at edge of CONUS coverage, except for South Florida.
[c]Clear weather reference for fade measurements.
[d]Not applicable.